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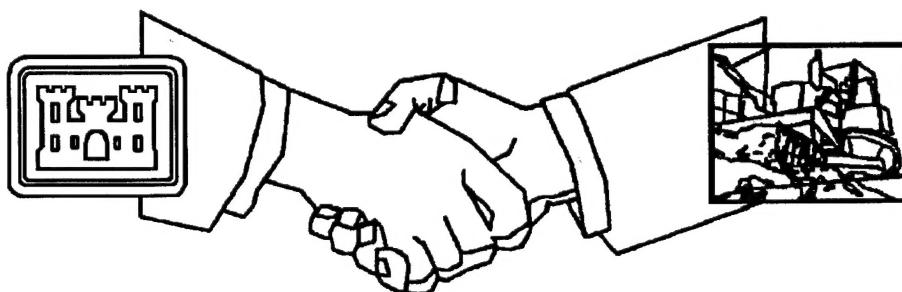
CONSTRUCTION PRODUCTIVITY ADVANCEMENT RESEARCH (CPAR) PROGRAM

Falling Beam SoilSaw™, An Advanced Process
for Forming Underground Cutoff Walls

by

Roy E. Leach, R. Kent Saugier, Earnest E. Carter

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A Corps/Industry Partnership to Advance
Construction Productivity and Reduce Costs

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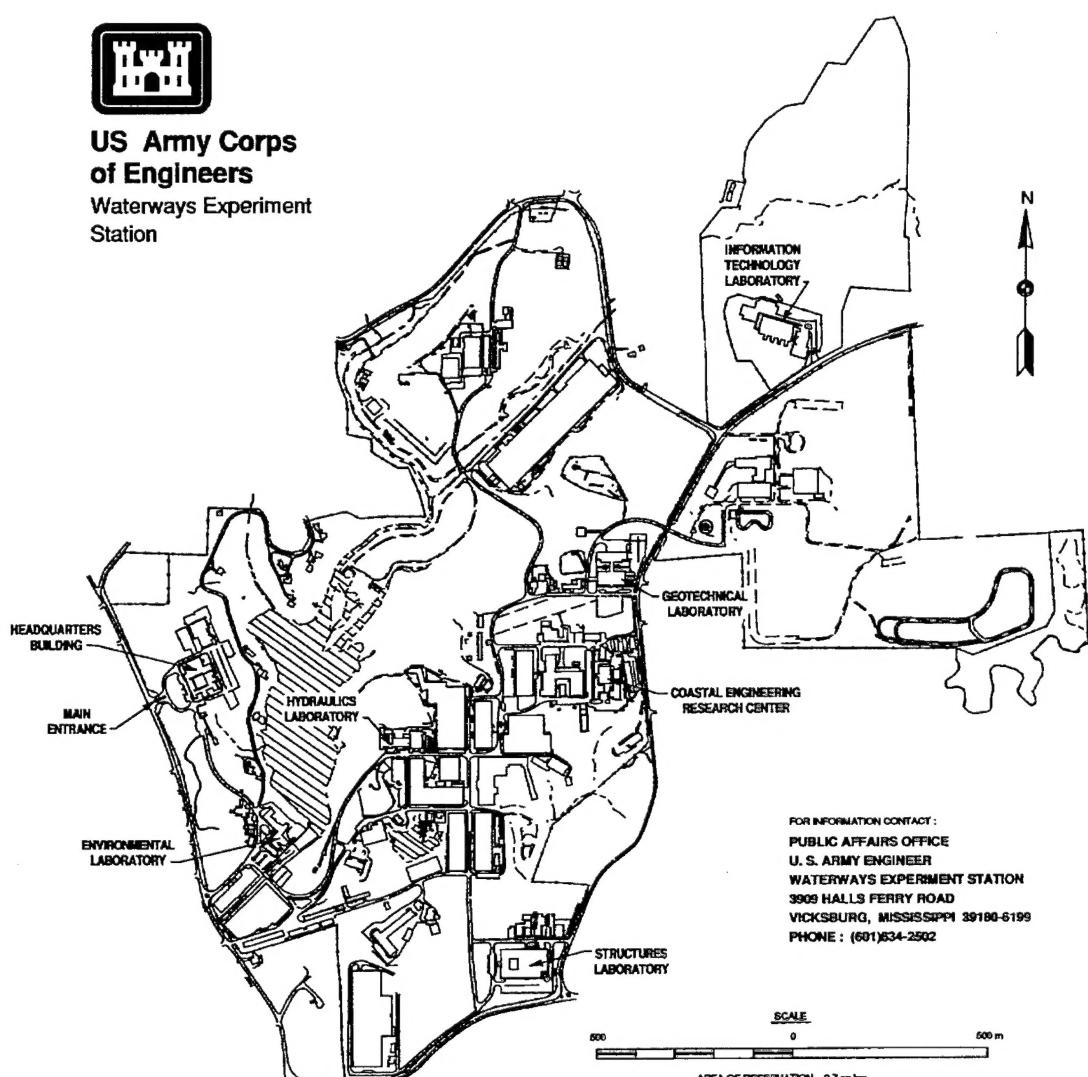
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Preface

The study reported herein was conducted as part of the Construction Productivity Advancement Research (CPAR) Program. The study was conducted by the Geotechnical Laboratory (GL), U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, for Headquarters, U.S. Army Corps of Engineers (HQUSACE), in conjunction with the industry, Halliburton NUS Environmental, Houston, TX. The HQUSACE Technical Monitors were Messrs. A. Walz, J. Vredenberg, D. Chen, and T. McDaniel.

This study was conducted under the general supervision of Dr. W. F. Marcuson III, Director, GL, and Dr. D. Banks, Chief, Soil and Rock Mechanics Division (S&RMD), GL. This report was produced under the direct supervision of Mr. W. M. Myers, Chief, Soil Mechanics Branch (SMB), S&RMD. Personnel engaged in the oversight, collection, and compilation of data for this study included Messrs. Ralph Cameron, John Sisley, and Leo Santa Cruz, U.S. Army Engineer District, Sacramento. Wahler Associates, Palo Alto, CA, collected samples, performed laboratory tests, and prepared Appendices A and B. This report was prepared and coauthored by Messrs. Roy Leach, S&RMD, and R. Kent Saugier and Earnest E. Carter, Halliburton NUS Environmental, Houston, TX. This report is the final report for the CPAR project entitled "Falling Beam SoilSaw™, An Advanced Process for Forming Underground Cutoff Walls."

During the publication of this report, Dr. Robert W. Whalin was the Director of WES. COL Bruce K. Howard, EN, was the Commander.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	0.00001638706	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
gallons (U.S. liquid)	0.003785412	cubic meters
horsepower (550 foot-pounds force per second)	745.6999	watts
inches	0.0254	meters
inches	25.4	millimeters
pounds (force) per square foot	6.894757	kilopascals
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per gallon	119.8264	kilograms per cubic meter
square feet	0.09290304	square meters
square inches	0.00064516	square meters
tons	907.1847	kilograms
tons (force) per square foot	95.76052	kilopascals

1 Description of Research and Development Partnership

In February 1993 as part of the U.S. Army Corps of Engineers' (USACE) Construction Productivity Advancement Research (CPAR) Program, the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, and Halliburton NUS Environmental, Houston, TX, entered into a CPAR Cooperative Research and Development Agreement (CPAR-CRDA). The purpose of the research under this agreement was to fully develop and commercialize SoilSaw™ technology for use in underseepage control (pre- and postconstruction), slope stabilization, and as a method of containing contaminants at hazardous waste sites.

CPAR is a cost-shared research and development partnership between the USACE and the U.S. construction industry, academic institutions, or other public or private entities who are interested in construction productivity and competitiveness. CPAR is designed to promote and assist in the advancement of ideas and technologies that will have a direct positive impact on construction productivity and project costs and on USACE mission accomplishment. The CPAR Program has received strong support from the U.S. construction industry with numerous projects funded since the program was initiated in 1989.

This research was conducted jointly by the Waterways Experiment Station (WES) and Halliburton NUS Environmental, Houston, TX. Halliburton NUS designed and modified the SoilSaw™ equipment, developed the technology, and installed the test trench. The USACE District, Sacramento (SPK), supplied the site and assisted with the oversight. Wahler Associates, CA, assisted in retrieving samples and performed all the sample testing.

2 Introduction

Background

In the construction of civil structures for containing surface waters or contaminated groundwater, it is often required that a low-permeability wall be constructed underground. One engineered construction technique used to install in-place walls is called slurry trenching.

The Slurry Wall Method, the most common method of forming barrier walls underground, is well known but has some quality problems in that it is difficult to tell if material from the side walls of the slurry trench have sloughed prior to or during placement of the backfill. Work in a loose noncohesive soil is especially difficult due to sloughing. Surface mixing of the backfill using bentonite and water is a very messy operation that can not be performed in freezing weather. Depth is limited to the mechanical reach of the excavator and generally requires greater widths for greater depths. Clam shell excavating equipment can extend the depth capabilities, but the production rates fall and the costs and quality problems increase dramatically with depth.

In general, a trench of the desired configuration is excavated using a bentonite and water slurry to support the sides. The trench is then backfilled with materials having a far lower permeability than the surrounding ground. The backfill in the trench could consist of soil-bentonite (SB), a mix of small amounts of bentonite and soil materials. SB is usually the trench spoils. Another backfill is a cement-bentonite (CB) mix where the trench is excavated using a slurry of portland cement and bentonite which is left in place to set and harden to form a wall. Also, concrete walls can be formed by placing concrete in the trench displacing the slurry.

Several alternative methods of forming barrier walls have appeared in current practice. Sheet piles are steel sheets that are driven into the ground to form an interlocking wall. The joints between sheets are typically not water tight and are difficult to verify as continuously interlocked.

The vibrating beam method uses a wide flange steel beam driven into the ground by a vibratory hammer. The beam is then extracted while grout is injected into the resulting cavity. The problem is that the soil may flow back

and pinch out the grout or the next adjacent beam intrusion may not follow the previous track to full depth.

Mixed-in-place barriers have been formed using multiple ganged auger tools which inject a grout slurry while mechanically cutting and mixing the soil in situ. These systems are a major improvement, since they mix the wall in place with a measured amount of grout slurry. In some soils, these systems may tend to cut the soil into chunks and not achieve a uniform mix. It is also difficult to assure continuity of the wall at greater depths since mechanical stiffness of the auger shaft is limited. To have evidence of continuity, a secondary mechanical proving operation is required.

Jet grouting is also a mixed-in-place method but offers a very uniform mixing not possible with mechanical augers. However, it also suffers from uncertainties in verifying continuity of a barrier wall due to possible deflection of the jetting pipe. The method is also relatively slow, and therefore costly.

Some inherent problems including continuity of the wall, condition of the wall where it keys into an aquiclude, and overall permeability can exist in installing a slurry wall by present conventional methods. Construction methods and procedures are needed that will not only solve these problems but that will be timely and cost effective.

The SoilSaw™ Barrier System is a true mixed-in-place method of forming barrier walls that forms barriers of high uniformity and offers a self-proving action that mechanically demonstrates continuity of the wall. The process is also very fast and not nearly as messy as conventional slurry trenching. The speed of the SoilSaw™ Barrier System gives it the potential to significantly lower the cost of long barriers.

Objective

The Falling Beam SoilSaw™ is a method for forming a continuous barrier wall at depths between 30 and 120 ft deep. The objective of this project was to fully develop and commercialize SoilSaw™ technology for use in underseepage control (pre- and postconstruction), slope stabilization, and as a method of containing contaminants at hazardous waste sites. Specifically, the objectives were to install a demonstration wall using the SoilSaw™ technology, determine the physical dimensions (width and depth) of the wall, and determine the in-place properties (permeability and strength). Wall specifications were: (a) permeability equal to or less than 10^{-6} cm/sec, (b) wall width equal to 12 in., (c) wall depth for Phase 1 equal to 30 ft and Phase 2 equal to 120 ft and (d) unconfined compressive strength equal to or greater than 15 lb/in.² (psi).

During the time frame of the CPAR study, several walls were constructed by Halliburton NUS for which USACE visually monitored but no strength or

permeability data were supplied. Therefore, the results of the objectives mentioned above will be based on the CPAR data presented in this report.

3 Description of Technology

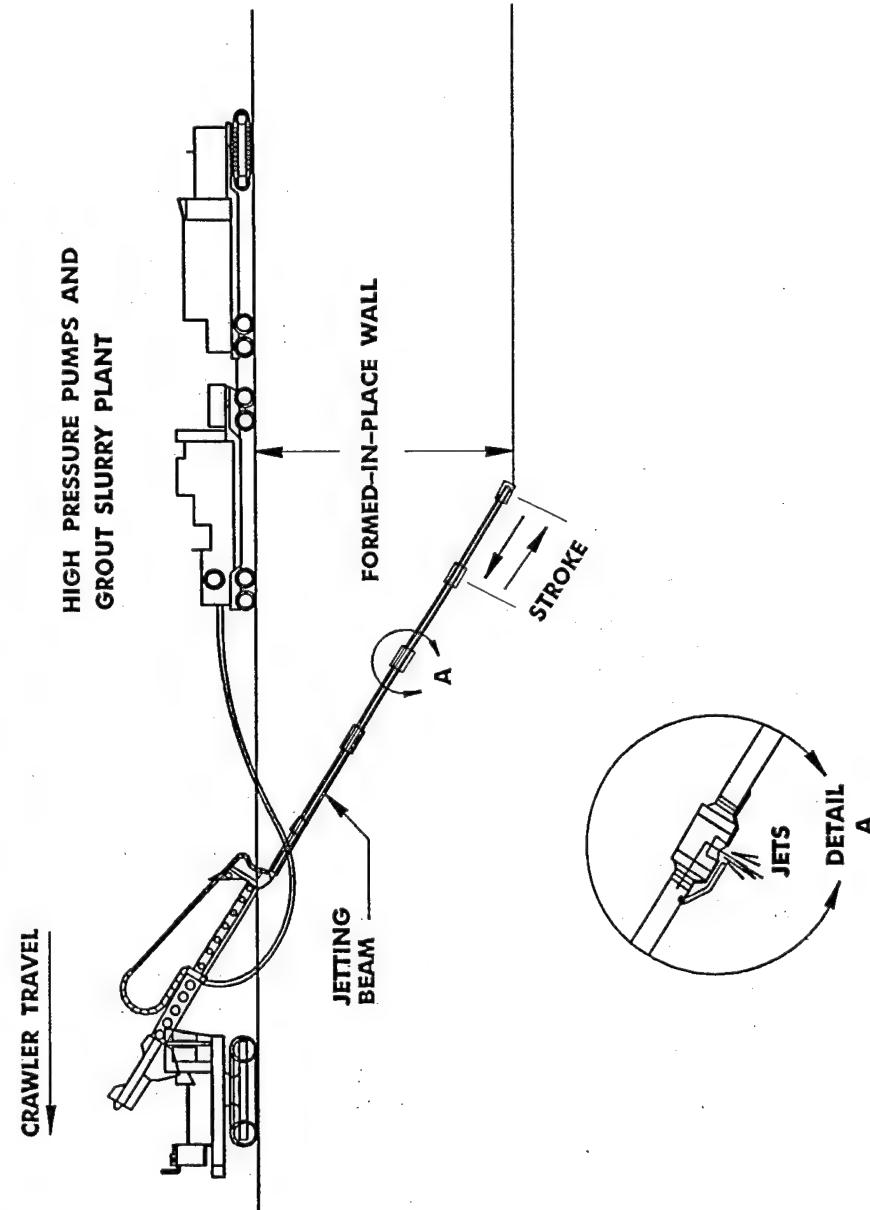
SoilSaw™ Barrier System

The SoilSaw™ Barrier System, Figure 1, is a means of creating an underground "formed-in-place" barrier wall without conventional excavation or backfilling. This new technology creates high-quality, "formed-in-place" barrier walls in a more continuous and verifiable manner than the two-step, "excavate and replace" methods of conventional slurry trenching or other types of in situ construction, i.e., mechanical drilling and mixing.

Soils in the path of the rigid jetting beam are pulverized in situ and temporarily liquefied by high-energy jets of a permeability modifying reagent. This reagent is typically a bentonite slurry or a cement/bentonite slurry but could also be any liquid material. Barriers can be formed using a variety of reagent materials or mixtures of reagent materials such as bentonite, cement, flyash, special wax emulsions, polyacrylates, and other materials.

When the SoilSaw™ jetting beam is reciprocated, the soil under the beam is liquefied along the entire length of the beam forming a viscous (10-in. to 1-in. slump) material as the beam sinks into the ground on its free end, Figure 2. As the beam reaches its working angle of about 30 to 45 deg, the crawler machine begins to move forward to maintain the angle of the jetting beam, and thus, the depth of cut. As the soil under the beam is mixed with the jetted slurry, it liquifies to a mortar-like consistency. The jetting beam's weight causes it to sink through the processed soil/grout mixture and remain pressed against the work face. The trench width is determined by the pattern of the jets and based on economics and a perceived acceptable minimum width, the present SoilSaw™ beam setup cuts a 12-in. width.

Sensors connected to a computer on board the crawler machine continuously record the jetting beam angle, crawler position, reagent slurry pressure and density. The beam angle data allows the true depth of the wall to be accurately computed. High-pressure grout slurry is supplied from mobile pumping equipment which moves ahead of the SoilSaw™ crawler unit. When the crawler unit completes a section of wall, the jetting beam is pulled out of the hole and cleaned. To ensure a seamless barrier wall, restart of construction begins by overlapping the previous construction by an amount that assures remixing to the full depth of the previous wall.



SOILSAW BARRIER SYSTEM

Figure 1. SoilSaw™ Barrier System schematic

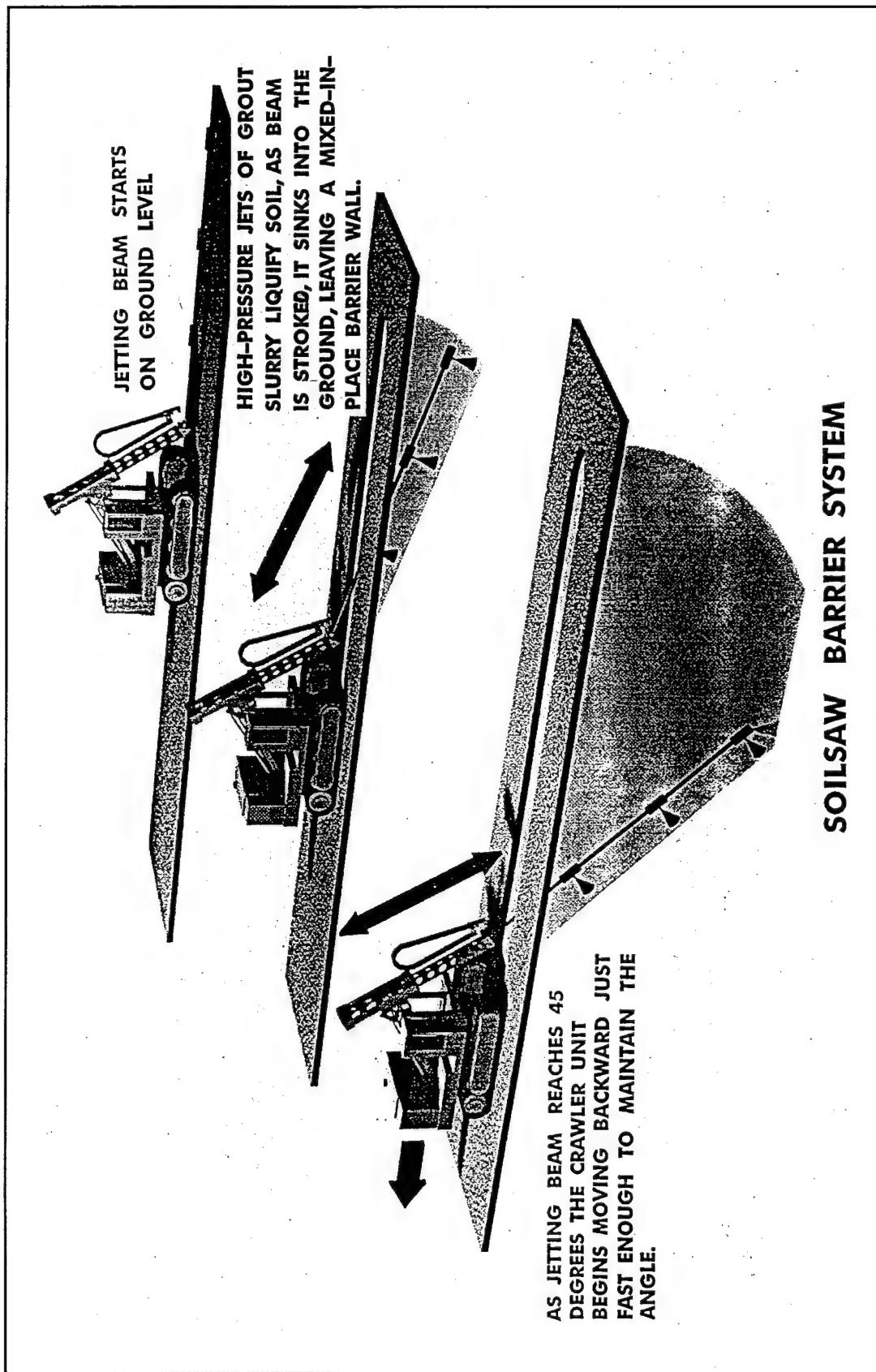


Figure 2. SoilSaw™ operating schematic

Equipment

The SoilSaw™ Barrier System consists of a jetting beam, a crawler platform, a slurry mixing plant, a slurry feed pipeline, pumping equipment, and slurry quality and process data collection equipment. In general, the slurry is mixed at a batch plant, is fed in low pressure lines to the high pressure pumps, and is then fed to the beam at high pressures as the beam cuts into and through the soil.

Jetting beam

The SoilSaw™ Barrier System jetting beam is a modular design consisting of a 6-3/4-in. outside diameter by 3-in. inside diameter heavy pipe with enlarged 12-in. diameter spools between each modular beam section of pipe, Figure 3. These sections are 13 ft long on the prototype machine. The spools have a removable sub with a transverse row of jet orifices across the flat bottom, which are directed downward. A pattern of seven parallel jets, 1.5 in. apart across the 12-in. width and perpendicular to the length of the jetting beam, was used. The jetting beam has a central conduit, connecting to all of the jets along the beam, that is supplied with high-pressure slurry from a pair of high-pressure hoses running from the pressure pumping equipment. The jetting beam itself has no moving parts and is quite rugged. The width of the wall can be changed by replacing the jet subs and optimizing the width of the spools (or the subs) and the angle of the jets. Specified wall widths, generally a minimum of 18 to 24 in., are often sized according to the available equipment that can attain the specified depth, to the type of soil at the site, to the purpose of the wall, and to a perceived safety factor. Wider walls consume proportionally more horsepower and grout slurry and are therefore more expensive.

Crawler work platform

The jetting beam is attached to a mechanical crawler machine at the upper end which has means to reciprocate the pipe along its length through a stroke equal to the selected spacing between the rows of jets. The pipe is free to pivot in the vertical at the point it is attached to the crawler machine, Figure 4.

In the first three tests, the jetting beam was mounted on a Gradall 880 crawler. The Gradall has a pivoting arm which can telescope through a 13-ft stroke and has crawler tracks to pull the jetting beam along. After the third test, the Gradall was abandoned and the jetting beam system was installed on a modified Caterpillar D-9 crawler, Figure 5. This unit is much larger and offers about four times as much power for stroking the jetting beam.

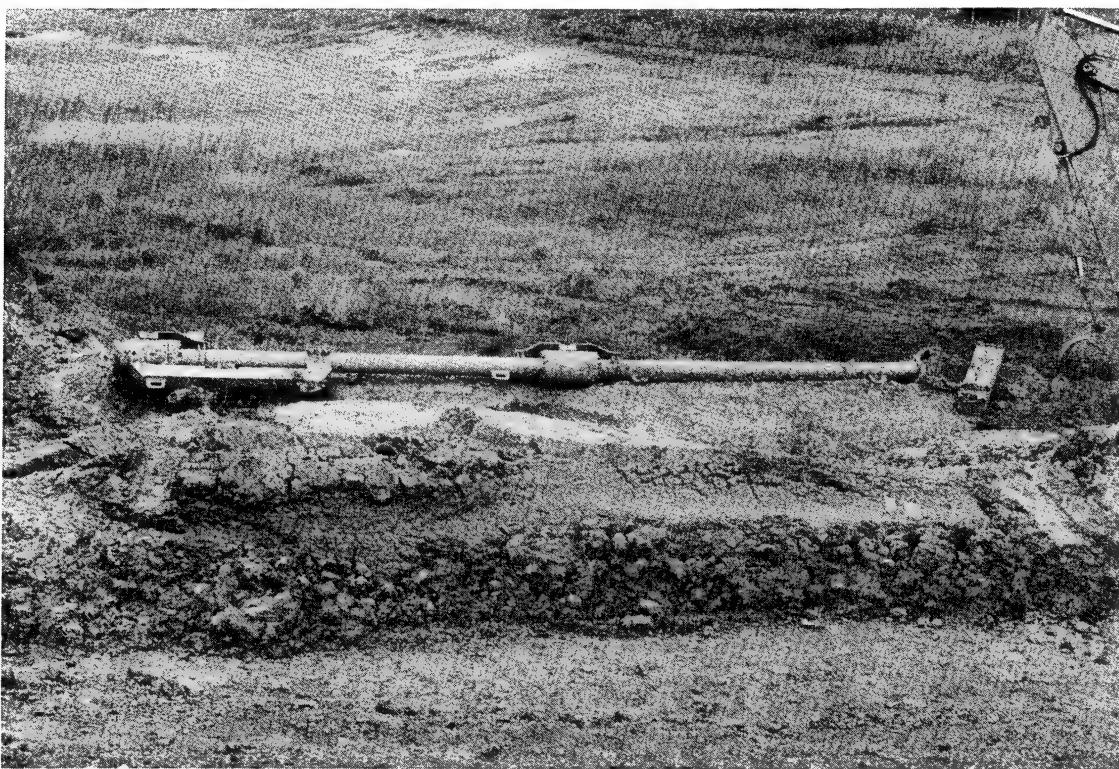


Figure 3. Beam configuration



Figure 4. Gradall 880 mechanical crawler platform



Figure 5. Modified Caterpillar D-9 platform

Slurry mixing plant

The slurry mixing plant must provide a continuous supply of uniform high-quality slurry to the process. Configuration of the plant may vary with the design of the slurry to be used. The plant used in the CPAR test consisted of six 500-barrel tanks, one 50-barrel mixer tub, two bulk cement weigh scale tanks, and four bulk pneumatic storage tanks, Figure 6. After the CPAR test, a slurry filter system was added to remove small particles which could plug the jet nozzles, thus ensuring sustained total construction time and production rates.

Pipeline

Once mixed, the slurry was transferred through a low-pressure pipeline to the high-pressure pumps. On the second and third tests, the pipe was an 8-in. aluminum irrigation line, Figure 7. On later projects, a 4-in. high-density polyethylene (HDPE) line was used to connect the batch plant to the system. This line is available in 1,100-ft lengths on a power driven reel assembly. The pipeline's function could also be served by tanker trucks delivering slurry to the system.



Figure 6. Slurry batch plant



Figure 7. Aluminum irrigation line

High-pressure pumping equipment

The pumping equipment provides the energy that cuts and mixes the soil. The equipment is standard oil field cementing and fracturing equipment provided by Halliburton Services, Figure 8. In the first two tests, a single 900-horsepower unit was used. In the later tests, a pair of 900-horsepower units was employed. The pumping units are capable of pressures in excess of 15,000 psi. However, the flexible hoses used to deliver the slurry to the jetting beam are generally limited to a working pressure of 5,000 psi.

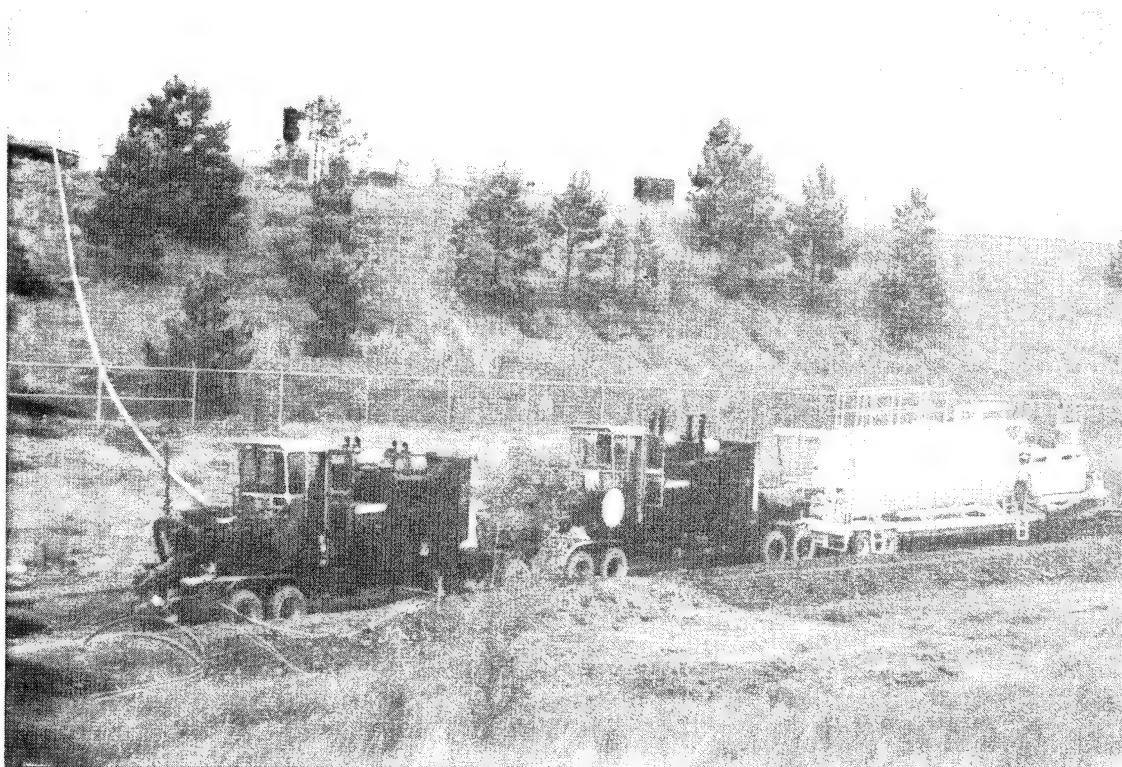


Figure 8. High-pressure pumping equipment

Slurry Design

The slurry is an engineered product which is designed to remain flowable in the process equipment but to thicken or harden once it is mixed with the soil to produce the properties desired. For cement/bentonite slurries, a special combination of set retarders and viscosity reducing agents is used. Many different slurry designs are possible according to the project objectives.

The slurries used in the CPAR test were a cement/bentonite (C/B) slurry and a cement/bentonite/flyash (C/B/F) slurry. The specific mix design is described in the slurry formulation section. In general, a grout slurry should have at least an 8-hr set delay. The slurry must have a low enough viscosity

so that it can be pumped through the jet nozzles but viscous enough that the solids do not settle out when the slurry is held static in the lines. The C/B slurries selected for this test were considered to be the lowest cost material able to meet specifications for permeability of 10^{-6} cm per second and for compressive strength of 15 lb/ft² (psf). The C/B/F slurry is designed to form a concrete-like hard structural wall which will be significantly more impermeable, after several months of cure, than the C/B wall. No soil/bentonite walls were planned for the CPAR test.

Sampling Methods

Determination of permeability of a slurry trench is a subject that has resulted in the formation of an American Society for Testing and Materials (ASTM) committee to determine state-of-the-art and/or a standard method. Also the USACE, under a civil works research program, will try to determine an acceptable method that can satisfy future project specifications. Presently, in the absence of large-scale tests of the entire slurry wall, permeability tests of undisturbed samples taken from the wall are required in numerous specifications as proof of construction. Because of some concern about obtaining "undisturbed" samples of C/B walls in the 50 psi to 200 psi compressive strength range, several undisturbed samples were collected by the "block" method described below and are identified as "block" samples in the results. Samples taken by conventional methods, described in Appendix A, are identified as "undist" (using pitcher barrel sampler) or "tube" (pushing a Shelby tube).

In the block method, Appendix B, an excavation is made along the sides of the wall and a cubic foot size block of the wall is removed. This block is turned on its side and cut into a cylinder which will fit into a 5-gal bucket. The bucket is then sealed and transported to the testing lab. The lab technician hand trims a cylindrical test specimen from the block for testing in a permeability cell as described in Appendix B. Due to the limited amount of slurry wall that was actually installed under full operational conditions (no Quality/Control (Q/C) problems) only limited data were collected by either of the three methods chosen for sampling. At this point in the project scheduling, it was apparent that there would have to be another wall installed to satisfy project goals, and the amount of sampling was sufficient. No investigation of differences in sample quality was made among the block method, Pitcher barrel sampler, and conventional push tube methods.

Another method for estimating permeability of the finished wall requires immediate sampling of the soft slurry in the installed wall. Bulk samples were taken using a PVC pipe sampler which sucked up a sample from a specific depth like a syringe, Figure 9. After a discussion, between Halliburton NUS and USACE, of the procedure to use for collecting and preparing bulk samples, it was decided that a Halliburton NUS technician would prepare the samples, with USACE oversite, according to techniques practiced at numerous



Figure 9. Bulk slurry sampling device

walls. These samples were initially allowed to pour out into a shallow bucket. The 2.5-in.-diam plastic molds are small, therefore, small rocks or clumps of hard material were either discarded or broken into finer particles. The samples were then poured into the molds, rodded, and tamped to remove any entrapped air, and then refilled (generally 1/4 to 1/2 in.) to the top of the mold. The samples were then sealed, labeled, and transported to a storage area.

Operation Monitoring/Data Collection

Data collected for system control of the power platform included monitoring the position and speed of the crawler, pump pressure, flow rate, slurry density, and jetting beam angle. Together these data fully describe the resulting wall construction process. The data are displayed in the equipment operators cab for use in controlling the construction process and are collected and recorded on a remote PC based system. The data can be monitored in real time on the remote PC and can also be printed out or downloaded to a floppy disk for analysis by a commercial PC database program.

4 Field Tests

Field Test No. 1, Rush Springs, OK

The first field test of the SoilSaw™ Barrier System was conducted by and for Halliburton NUS in July 1992 in a farmer's field near Rush Springs, OK. The USACE did not monitor this test. This site was selected due to its deep, sandy soil, which was thought to simulate soil characteristics typical of those present in the levees along the Sacramento River near Sacramento, CA. The SoilSaw™ was developed to augment a current contract in force in 1992. Borings located at the Rush Springs test site indicated that the Standard Penetration Test (SPT) values varied from 0 to 15 blows/ft, representative of very loose to firm sandy soil.

The Jetting Beam hardware was installed on a Gradall 880 telescoping boom excavator crawler (Figure 4). The Gradall was modified with a special hydraulic valve automatic stroking system that, when activated by a toggle switch, would continuously stroke the jetting beam while crawling the machine forward. The crawl rate of each track was adjustable by valves in the cab to allow the machine to turn.

The machine was tested with various lengths of jetting beam and various operating methods. Walls were formed at depths up to 34 ft over a period of 3 weeks. No cement retarders were used due to the added cost. Problems with trash, such as rust flakes, rocks, and plastic, in the jet nozzles and the slurry filters occurred. This was addressed by placing a cyclonic cleaning system between the mixer and the pumps. Whenever a problem was encountered, it would usually force a shutdown that required washing all the cement out of the equipment generally consuming the rest of the work day.

Production rates of about 3 lin ft/min were typical for the Oklahoma site. On 6 August 1992, a 130-ft-long by 34-ft-deep run was completed in 44 min. Total slurry pumped was 37 percent of the trench volume. Overflow was about 7 percent of trench volume. A 9-lb-per-gal slurry was pumped at six to eight barrels per minute at pressures varying from 1,500 to 3,600 psi at a jetting beam angle of 32 deg. In this type of soil, the SoilSaw™ Barrier System performed at very high production rates, up to 5,000 sq ft/hr, with minimal spoil returned to the surface.

The jets cut through this soil so easily that the operator had to exercise caution to prevent the beam from descending past the design operating angle of 32 deg. At one point, the beam cut down to about 45 deg which was too deep for the Gradall to continue stroking. The beam had to be retrieved with the aid of a 75-ton crane.

To reduce the cost of the tests, a light weight 50/50 dry blend of bentonite and API class H cement was used. This material was mixed to a lightweight slurry of 9 to 11 lb/gal for most of the tests. After the C/B wall, a C/B/F slurry mix using a 50/50 blend of class F flyash and class H cement mixed to 12 lb/gal was used. The walls formed, of both types, were later excavated and had similar unconfined compression strength and permeabilities. The slurry designs for these walls were not intended to form an impermeable wall but rather to develop just enough mechanical strength to demonstrate the placement method. An open trench transverse to the test slurry walls was excavated and the soil was then excavated from beside the walls, Figure 10. The sandy soil tended to fall away from the walls exposing a smooth surface. There was no color difference between the walls and the native soil, therefore, a pH sensitive dye was used to make the walls turn red for delineation purposes, Figure 11. The wall material was soft enough to cut and shape with a hand spade.

Field Test No. 2 (CPAR), Sacramento, CA

The second field test of the SoilSaw™ Barrier System as conducted on a dry levee surrounding a USACE dredge containment area in West Sacramento, CA. This was the CPAR test monitored by the USACE. This site was selected to simulate typical soil characteristics and working conditions of those present in the levees along the Sacramento River near Sacramento. The near-surface soils here were very sandy and were similar to the soils of Field Test No. 1. Two borings (under contract to Halliburton NUS) located in the levee approximately 500 ft apart but outside the final wall stations were taken to determine the soil classifications, layering, densities, and strengths. Results, reported by Halliburton NUS, showed SPT values from 7 to 29 in exploratory boring B-1 and 7 to 17 in boring B-2. These values are representative of loose to very firm cohesionless material, Table 1. "After construction" borings performed by Wahler and Associates and reported in Appendix A indicated the levee was mostly silty sand and sandy silt interspersed with sand lenses. The general profile of the levee was 2 ft of very loose sand (SPT 3 to 4), underlain by a 3-ft layer of firm silt (SPT 5 to 9), underlain by a 7-ft layer of stiff silt (SPT 9 to 14), with a very stiff silt containing sand seams (SPT 14 to 24) continuing to the bottom of the borings near 20 ft deep. Borings B-2 and B-7, the deepest postconstruction borings, showed a layer of clayey silt from 21 to 24 ft at Station 2 + 10. For more detail, see the boring logs in Appendix A.



Figure 10. Excavated slurry wall, Oklahoma

The CPAR demonstration test was initiated in the hard soils near Halliburton NUS boring B-1. The jetting configuration which had been quite effective at Rush Springs was not able to penetrate the denser soils of the levee. When the SoilSaw™ was started, it sank into the loose surface sands rapidly and then stopped when it hit the stiff soils about 5 ft deep. The beam slowly cut down to a maximum depth of about 14 ft (near the top of the very stiff silts) but did not appear to be working efficiently. The unit was pulled out for examination. Several jets were plugged with foreign material which had bypassed the cyclone separation filter.

After decontaminating and flushing the system, the cutting operation was restarted. Again, the unit descended to a depth of about 12 ft and stopped. Operators began moving the unit backward at a rate of about 2 lin ft/min. The jetting beam continued to descend slightly, but never exceeded a 19-ft depth.

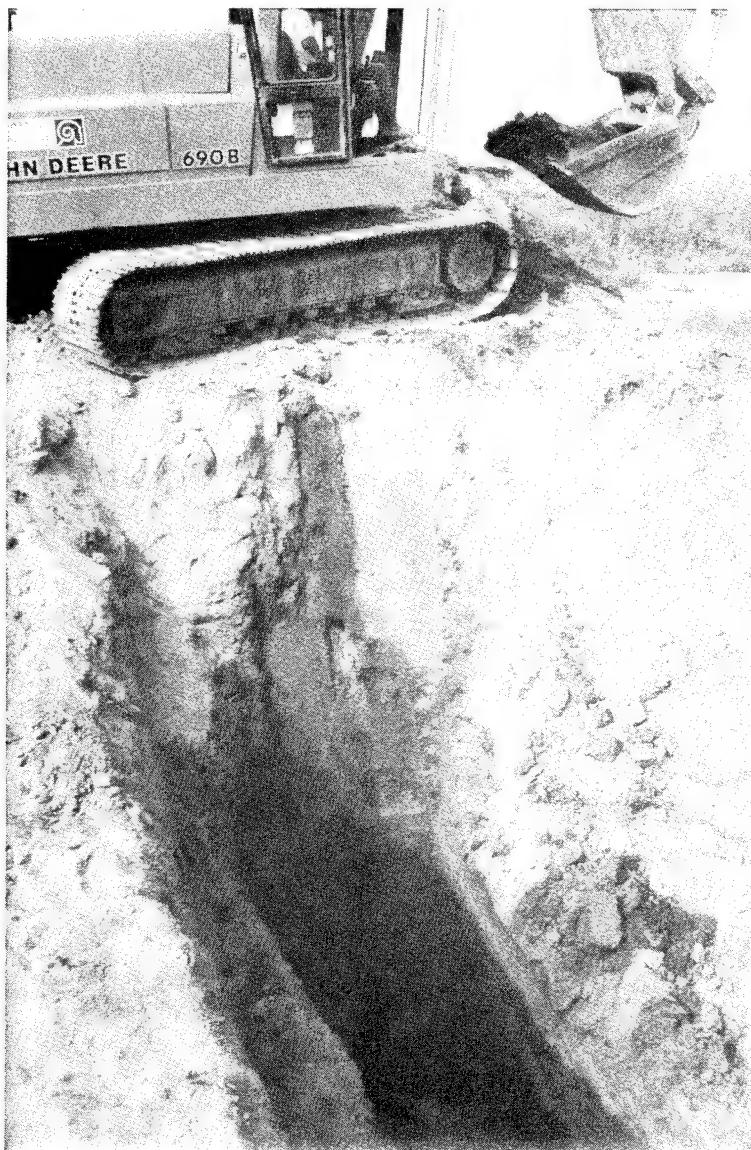


Figure 11. Visually enhanced dyed slurry wall

It now seems apparent that the jet pattern used in this test was too widely spaced to completely disrupt the denser material. The true nature of the problem was not recognized because of the plugging of several jets due to foreign matter in the cement slurry. The foreign matter turned out to be an expanded perlite material which is lighter than water and was able to get past the cyclone separator. A problem with moisture getting into the computer called into question whether the tool was receiving the proper pressure. These factors all combined to reduce the conclusiveness of each theory about what prevented the system from operating properly. The SoilSaw™ did form high quality walls but did not demonstrate the ability to reach the desired depth or operate at the speeds expected.

Table 1
Soil Stratigraphy

Bore No.	Depth (ft)	Soil Description and Classification	Blows/ft	Remarks
B-1	0-15	Sandy silt (ML) Sand (SW) med-dense	27/29	Wall not placed near either of these locations.
	15-29	Sandy silt (ML) fine grained sand	18/17/7	Sand decreases significantly below 23 ft.
	29-36.5	Silty clay/clayey silt (CL-ML) med stiff to very stiff	10-17	
B-2	0-20	Sandy silt (ML) med. dense with fine grained sand	14/15/17	
	20-25	Sand (SW) sandy silt med. dense	9	
	25-26	Clay soft	6	
	26-36.5	Silty clay/clayey silt (ML) med. stiff to stiff dense	15-10	
Levee materials: The levee was comprised of silt, with some fine-grained sands. The upper 2 ft of the levee consisted of a layer of loose, fine-grained sand. Below this surface layer, the levee materials consisted primarily of stiff to very stiff, dark yellowish-brown sandy silt with mixed layers of medium-dense, fine-grained sand and silty sand. Native material was apparently encountered at depths of between 19 and 22 ft below the levee crown and consisted of stiff silt and medium dense silty sand.				

Many questions were answered during this test regarding the batch plant operation. More importantly, the effect of the SoilSaw™ Barrier System on existing fractures in earthen levees was derived. During the water system flush test, an existing fracture (or rodent hole) was encountered in the levee. Water flowed freely through this fracture at an estimated 40 to 60 gpm. When the slurry was turned on and the jetting bar of the SoilSaw™ Barrier System cut through the fracture, it was sealed immediately with less than a cubic yard of the blended soil being spoiled out of the side of the levee.

Slurry Formulation

Two basic slurries were used in the CPAR test. The first was a C/B slurry and the second was a C/B/F slurry. The cement/bentonite formed a dense clay-like product slightly softer than the native soil which could be trimmed with a shovel. The cement/flyash slurry made a rock hard product.

The jetting slurries were based on a prehydrated, 6-percent bentonite gel. The slurry was then modified with various amounts of cement, flyash, and lignosulfonate admixtures as shown in Table 2 and described below:

Table 2
Mix Design

Slurry No.	Bentonite Concentration	Density No./Gal	Cement Concentration	Flyash Concentration	Additive No. 1	Additive No. 2	Remarks
1	22 lb/bbl				2.9 lb/bbl		
2	22 lb/bbl		100 lb/bbl		2.9 lb/bbl		Additive No. 1 Lignosite
3	22 lb/bbl		100 lb/bbl	295 lb/bbl c/b		.68 lb/bbl	Class F flyash Additive No. 2 CFR-3

- a. The base bentonite gel was prepared by blending 21.4 lb of premium grade bentonite with 2.8 lb of dry lignosulfonate and 39.9 gal of water. This mixture was prehydrated for 24 hr in tanks.
- b. Then, the C/B slurry was prepared by blending 37.3 gal of the above gel with 0.6 lb of CFR-3 (a super plasticizing admixture) and 88.7 lb of Type I portland cement.
- c. The C/B/F wall starting at Station 0+00 was made by adding 231.7 lb of class F flyash to 32.9 gal of the above C/B slurry.

Production Data

Best production rates during the Sacramento test were approximately 2,100 sq ft/hr (2.2 ft/min at a 14-ft depth) using a 900-hp pumping unit. It should be noted that this production rate is believed to be a result of a non-optimal configuration of the jets which was not suited for the soils encountered. This nonoptimal jet configuration is also believed to have prevented the jetting beam from sinking to the desired operating depth.

Barrier(s) Constructed

On 4 March 1993, after several attempts were aborted due to Q/C problems, a wall approximately 150 ft long by 1 ft wide by 14 ft deep (depth determined using a 1-in. steel pipe) was installed in approximately 1 hr, Figure 12. The work was stopped because, as noted above, the nonoptimal jet configuration was not cutting properly, some of the jets were clogged, and the beam was not reaching the original specified 30-ft depth. On 5 March 1993, the slurry was thinned considerably, another section of beam was added, and another section of wall was attempted. The SoilSaw™ had advanced about 75 ft when the automatic controls malfunctioned. The nozzles were allowed to pump slurry while repairs were made, but an attempt to restart the



Figure 12. Installed CPAR slurry wall, California

operation was unsuccessful (or canceled) due to fading daylight and lack of depth penetration by the beam. From 50 to 75 ft of wall was installed to a depth of 19 ft. The following day two sinkholes had formed at the approximate location where the jets were left running during the malfunction (Figure 13). No extensive investigation was attempted to explain the sinkholes but the soil/slurry ratio was undoubtedly low at the point of the sinkholes and the beam was removed from the trench within 75 ft of the sinkholes. Shrinkage due to the low soil/slurry ratio or displacement of slurry into the hole formed upon extraction of the beam could have contributed separately or together to the sinkholes. Halliburton NUS management shut the project down and demobilized the following day, 6 March 1993.

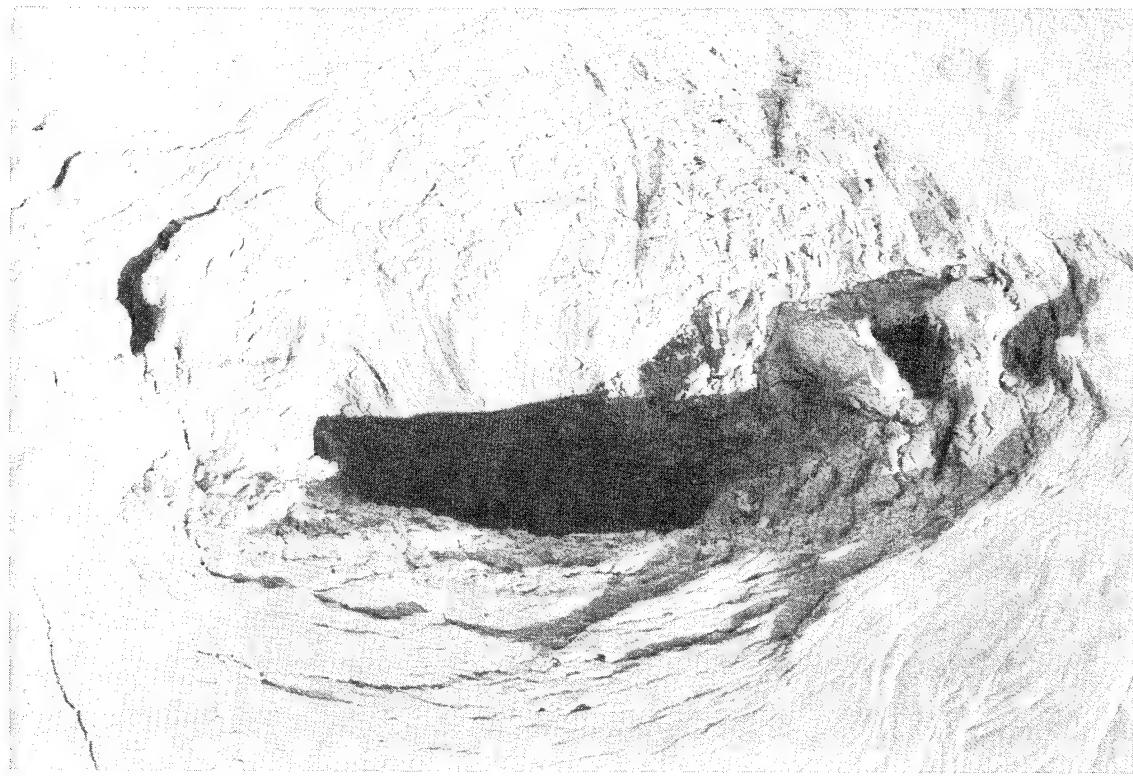


Figure 13. Sinkhole at Station 2 + 20, California

5 Excavation, Sampling, and Analyzing The CPAR Barrier

Visual Results of Excavation

After a delay of approximately 8 months resulting from an endangered hawk nesting in the area, a large tracked excavator was used to excavate the Sacramento levee in two major areas. The first excavation was made between Station 2+35 and 2+65 on the last portion of wall formed. This wall was constructed using a cement/bentonite mix. The wall was about the same color as the native soil and was estimated by Halliburton NUS personnel (at 246 days set time) to be about 10 tons/sq ft (tsf) in compressive strength. Laboratory tests on a bulk sample at Station 2+50 after a curing time of 28 days indicated a compressive strength of 1.63 tsf (22.6 psi), Table 3. A pH sensitive indicator solution (phenolphthalein) was applied to make the wall visible to carry out the excavation. This indicator solution was sprayed on with a garden pressure sprayer causing the alkalies in the cement wall to turn a deep pink color for about 10 min. Without this color indicator, it would be very difficult to distinguish between the wall and the native soil, Appendix B. The rough texture produced by normal bucket teeth made it hard to detect the wall, even with the dye indicator. Therefore, the excavation was accomplished with a flat-bladed bucket making it easier to distinguish texture and color.

The second excavation was made at the 0+50-ft location in an area formed with cement/bentonite and class F flyash. This wall was quite hard and looked much like concrete. Laboratory tests on a bulk sample at Station 0+50 for a curing time of 28 days indicated a compressive strength of 2.37 tsf (32.7 psi), Table 3. The excavator was able to dig on both sides of the wall and then break off a section about 6 ft square. This section was lifted out of the excavation and examined closeup. The material contained numerous flattened air pockets which averaged less than 1/2 cc in size. No mechanical deaeration device or chemical antifoam agent was used in preparing the slurries used in this test. Both the type of flyash used in this test and the admixture used tend to act as air entrainment agents. Lab tests of bucket samples of this material show a very low permeability, as shown in Table 3. The low permeability indicates that the air pockets are not connected.

Table 3
Permeability Table, CPAR West SAC, Sacramento, CA

Station	Slurry Type ¹	Depth (ft)	Sample Type	Sample Date	Test Date	Sample Holding Time (Days)	Age During Test (Days)	Perm Rate cm/sec	Strength (psi)	Remarks
00 + 25	3	8	Tube	03/12/93	03/30/93	18	26	1.2×10^{-6}	14.8	Walls installed on 3/3 and 3/4/93
0 + 50	3	13	Bulk	03/03/93	03/30/93	27	27	9.0×10^{-8}	32.9	
0 + 50	3	8	Block	10/27/93	11/04/93	8	246	8.0×10^{-8}		
0 + 57	3	8	Pitcher	03/13/93	04/01/93	19	29	1.7×10^{-6}	53.3	
2 + 00	2	8	Tube	10/27/93	11/17/93	21	259	2.2×10^{-6}		
2 + 50	2	15	Bulk	03/04/93	04/01/93	28	28	4.0×10^{-7}	22.6	
2 + 50	2	4	Block	10/27/93	11/04/93	8	246	2.8×10^{-7}		
2 + 50	2	10	Block	10/27/93	11/05/93	9	247	2.2×10^{-7}	.	

¹ See mix design table for slurry description.
 2 - C/B/F
 3 - C/B

After excavation of the wall, large blocks of the exposed wall were removed. The large blocks, as noted in the sampling description, were then cut into 12-in.-diam cylinders by hand and packaged in a sealed 5-gal bucket. The bucket samples were delivered to the testing laboratory where each was manually trimmed to size and tested for permeability as described in Appendix B.

The barrier properties were within anticipated values of permeability and compressive strength for the limited number of samples taken. But the samples did show some unexpected bubble shaped voids, believed to be attributable to air entrained in the slurry. These voids were saturated during laboratory testing, and the permeability results may not be what would be expected in the field. Differences would be proportional to the difference in field versus laboratory saturation. Also, there are discernable differences in lab permeabilities depending on the type of samples tested: block, tube, Pitcher barrel, or bulk.

During excavation the barrier appeared to be uniformly 12 in. thick with smooth sides. In two places, the excavation occurred near the same locations which had been core drilled by Wahler and Associates. Several tubular holes mentioned in the Wahler report, Appendix B, are described to be "large tubular voids," one of which was large enough to completely push a shovel into the void. Halliburton NUS personnel observed the holes were vertical and could be consistent with being formed by pushing a shelby tube or piston sampler into the wall. The core hole was clearly visible as a smooth vertical

tubular hole in the center of the wall. Station 2+50 was where the bulk sample was taken for the "installed" permeability sample and was also where the beam sat motionless down in the trench with the nozzles running approximately 15 min while an operational problem was corrected. Wahler Associates used borings in the trench at Station 2+10 to obtain the 28-day samples. The tubular holes appear to be associated with the bulk sampling or operational problems in that area and not likely an overall flaw of the SoilSaw™ procedure.

Summary of Lab Tests

The positive acting PVC pipe sampler was used to obtain wet samples of freshly formed wall from a specific depth. The bulk samples taken by USACE and a Halliburton NUS technician during construction were lab tested and exhibited a permeability of about 4×10^{-7} cm/sec for the C/B slurries and 9×10^{-8} cm/sec for the C/B/F slurry, Table 3. The measured permeabilities for the undisturbed push tube and Pitcher barrel samples were 1.2 and 1.7×10^{-6} cm/sec, respectively, for the C/B/F, wall while no samples were taken for the C/B wall. Sample age during the test was approximately 28 days.

Due to environmental concerns with hawks nesting in the general area, the final sample collection was delayed and the sample age during testing was approximately 246 days. Three of these samples were taken using the block method and one was a push tube sample. The permeability for the block sample of C/B/F wall was 8.0×10^{-8} cm/sec. The permeability for the block samples of C/B wall was 2.2 and 2.8×10^{-7} cm/sec while the tube sample was 2.2×10^{-5} cm/sec.

Unconfined compressive strengths for the C/B/F wall were 53.3 and 14.8 psi for the Pitcher barrel and tube undisturbed samples, respectively, and 32.9 psi for the bulk sample, Table 3. The strength for the C/B wall, determined using a bulk sample, was 22.6 psi.

6 Other Field Demonstration Sites

Field Test No. 3, Palestine, TX

The third field test of the SoilSaw™ Barrier System was conducted in June of 1993 in Palestine, TX. USACE personnel were invited to attend this demonstration as observers, but no samples were taken for laboratory testing. The problems experienced during the CPAR Field Test No. 2 with contaminated material in the slurry delivery system were solved by both installing additional positive filtration systems and enacting better quality control procedures for raw materials.

The clay soils at this site were quite hard with some SPT blow counts averaging up to 100 blows/ft. Some thin iron ore rock layers ranging in thickness from 3 in. to 1 ft were present. One section of wall was formed with a C/B slurry and another with a 6-percent prehydrated bentonite slurry. Bulk samples and excavated trimmed samples were tested by Halliburton NUS and within design parameters, although no data are available.

The equipment was fitted with a full spread of jets and an additional weight on the nose of the tool, Figure 3. Two high-pressure pumping units instead of one was used in this test, giving a total of 1,800 jetting horsepower available. This allowed a jetting pressure of about 5,000 psi.

The SoilSaw™ unit performed better in this test than in the CPAR Field Test No. 2, Sacramento, CA, achieving depths of about 23 ft and production rates of 2,800 sq ft/hr. The Gradall excavator lacked sufficient power to reciprocate the beam in the high-viscosity soil/grout mix being formed. The beam was slow to fall to full depth. In the latter half of the test, there were no rock layers in the soil profile and the beam cut significantly better. This resulted in several hundred feet of barrier being constructed during this test, but the lack of power was apparent. The Gradall would frequently stall on the upstroke and tended to lift the rear of its tracks on each up stroke. When bentonite slurry got under these tracks, the entire crawler stroked back and forth once while the beam remained stationary.

Excavations of this wall, Figure 14, showed it to be of uniform width and homogeneity to full depth. Three large excavations were opened up along the C/B wall, exposing a section of the wall about 40 ft long in each case. No voids or nonhomogeneous areas were observed in the wall. Though the soil has some rocks present, no rocks larger than 1 in were observed in the wall cross sections. Several push tube samples were taken with a Shelby tube pushed in with the backhoe. Several 12-in.-diam trimmed block samples of wall were also taken.

One cross section cut was made through the soil/bentonite wall. The wall material was a zero slump material which would slowly flow out of the wall into the excavation. This exposed the inside of the 12-in.-wide trench and provided opportunities to take photos of the cut that the SoilSaw™ Barrier

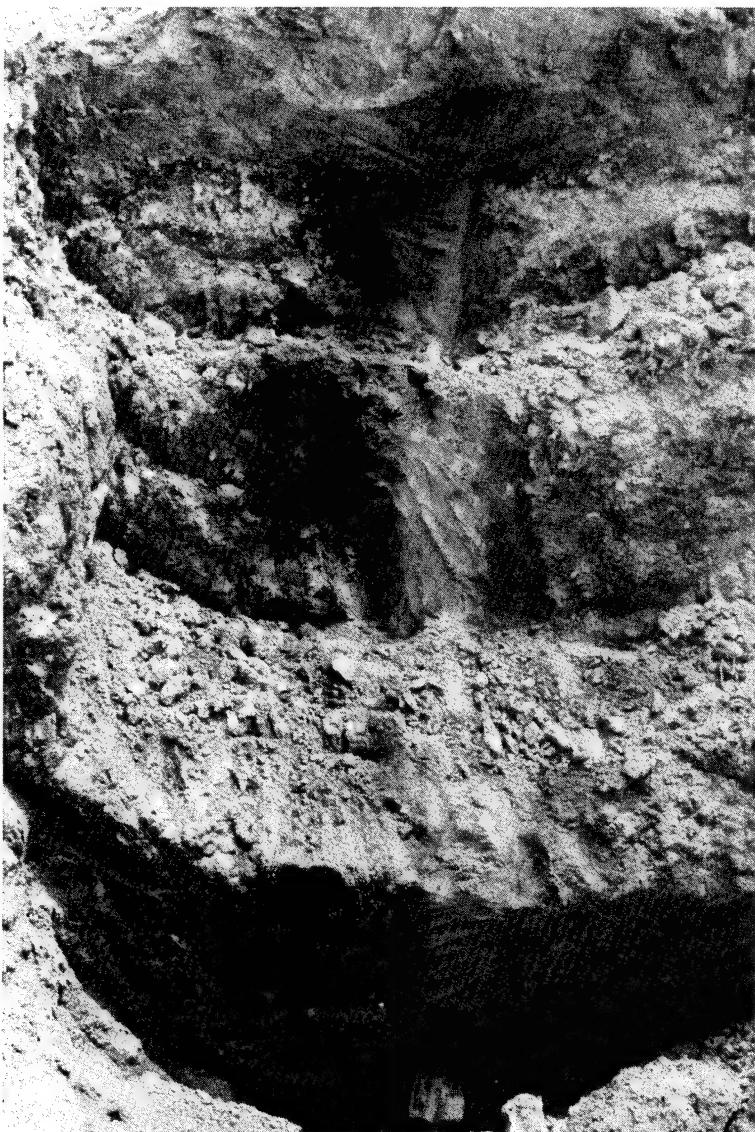


Figure 14. Excavated slurry wall, Texas

System makes through a hard soil. This cut was very uniform and appeared to be precisely 12 in. wide from top to bottom.

This test clearly indicated that the work platform based on the Gradall 880 was not sufficient to reach depths greater than 25 ft in clay soil (SPT values up to 100) due to the viscosity of the grout/soil mix overloading the stroking mechanism. The Gradall is a 50,000-lb class machine with a maximum stroking force of less than 20,000 lb. As a prototype, the SoilSaw™ Barrier System Gradall platform was useful but it became apparent that to operate at greater depths, significantly more stroking power was needed. The SoilSaw™ Barrier System's ability to make a high-viscosity product is very desirable but also creates very high frictional loading when the beam is stroked rapidly. The Gradall may still find use as a light-duty platform. For depths greater than 28 ft, a customized machine such as the D-9 based unit (Figure 5) recently constructed at Halliburton NUS will be needed.

Field Test No. 4, Pasadena, TX

The fourth field test for the SoilSaw™ Barrier System was conducted in Halliburton NUS' yard in Pasadena, TX. The purpose of this test was to evaluate new equipment rather than properties of barriers constructed. The Gradall 880 was eliminated as a power platform and the SoilSaw™ stroking mechanism was fabricated to fit on an existing D-9 Caterpillar tractor which was available from a previous project. This 150,000-lb unit had a 1,000-hp engine and could deliver 400 hydraulic horsepower to the stroking cylinders. This could allow up to 100,000 lb of stroking force for reciprocating the beam. The unit is capable of a 20-ft stroke but was used with the existing down hole equipment which is configured for a nominal 12-ft stroke.

Soil Survey

The soil at the site was a dense clay with very hard layers at increasing depth.

Slurry Formulation

These tests were performed with a 6-percent prehydrated bentonite slurry.

Production Data

The SoilSaw™ Barrier System operated continuously for almost 3 hr averaging between 1 and 1.5 lin ft/min and operated at depths from 25 ft to 45 ft.

It appears that production rates of 2,700 sq ft of soil/bentonite wall per hour are sustainable for a 5-hr period per day. Production improvements should increase this rate after the first month of experience.

Barrier(s) Constructed

Two parallel walls were constructed about 275 ft long with depths varying from 25 to 45 ft. No sampling or final analysis was made or planned for this field test.

Equipment Modifications

During this test the increase in stroking power eliminated problems with stroking the beam at greater depths. There was still some difficulty making the beam descend to the desire depth. This was addressed by adding extra weight to the beam and by increasing the number of jets to nine on each jet sub. These changes seemed to help but did not bring productivity up to the capability believed to be possible.

In response to the productivity problem, Halliburton NUS conducted a small research program to try to improve the efficiency of cutting clay soils by optimizing the jet configuration. Consideration was given to the elimination of the flexible link between the jetting beam and the stroking mechanism and allowing the entire assembly to pivot freely to help keep the jets flush against the face of the cut as the crawler rocks back and forth. These changes will be incorporated in future tests beyond the time frame of this report.

7 Discussion

The relative ease of the first test in Oklahoma was misleading when estimating the difficulties that might occur on the CPAR demonstration. Much was accomplished, but also major unexpected Q/C problems developed. The Hydrocyclone system was not an effective way to remove all the large particles from the grout system. The cleaning procedures for the pipeline system also needed improvement. There also should have been more significance attached to the potential difference between the Sacramento borings and the soils at the Rush Springs site. Excavation of the Sacramento walls showed the levee site to be made of silts, sands, and silty sands with strengths too hard to measure with a pocket penetrometer (> 4.5 ton/sq ft).

A major problem at the CPAR site was that the SoilSaw™ could not reach the desired cutting depth. The difficulty reaching the specified depth was due to the jet pattern used on the tools. A pattern of seven parallel jets, 1.5 in. apart across the 12-in. width and transverse to the centerline of the jetting beam was used. These jets may not have been able to cut a full width removing all the soil beneath the beam, but instead tended to cut seven grooves into the soil as the soil became increasingly stiff with depth. The nose section of the tool was configured with only three jets across the nose. The function of these jets was to clear the bottom of the hole where the beam could descend. In a cohesive soil, it is possible that the jets only cut a narrow groove as the jets repeatedly traverse the same path. Adding extra weight to the jetting beam helps by breaking down the ridges between jets. This problem may be overcome by using a pattern of angled jets which strike the soil in a different place as they sink further into the workface. Jet spacing, number, and angle were modified for Field Tests 3 and 4 improving the penetration but apparent lack of power was still a problem. A research project to further evaluate improvement is currently under way at Halliburton NUS.

Short walls were formed using various kinds of slurries and in all cases appeared to form a wall containing a uniform mix of the slurry and the native soil. No data was made available by Halliburton NUS on strength or permeability, therefore no data other than the CPAR data will be presented in this report. It should be noted that SoilSaw™ Barrier System technology provides a means of monitoring and recording the quality of both the slurry and the soil to slurry ratio. To assure high quality in a wall, these factors must be controlled. For example, if the jets are left running at full rate while the unit stops moving forward or stroking, the soil ratio would decrease and approach

zero. If the particular slurry design can not tolerate a zero soil ratio, then that section of the wall would require reworking. A part of the final product should be a report documenting the soil/slurry ratio actually placed all along the length of the wall.

The aluminum pipeline caused some problems with introducing particles into the system due to poor cleaning technique. Clean pipe and filters can solve this problem. Even with the contamination problem, the SoilSaw™ technology successfully demonstrated a workable process for delivery of slurry materials to the SoilSaw™ unit on a long levee. This procedure should allow operation of the system on long narrow right of ways with over a mile between batch plant locations. Although walls have been built on narrow right of ways as early as 15 years ago, it is believed that minimum material use and spoils will make the SoilSaw™ economically feasible.

In the CPAR test the computer system was subjected to rainfall during operation and failed to operate properly. The system was reconfigured in the next test and performed well. Future work on the system will include development of a PC database program to summarize and display the data in an easier to understand, graphical format.

It may also be possible to form permeable interceptor or treatment walls by use of foamed cement or temporary water gelling agents. In some cases it may be desirable to place a soil/bentonite wall using a higher concentration of bentonite in a well dispersed but nonprehydrated slurry. This would limit the viscosity of the slurry to be pumped while allowing the bentonite to hydrate in situ. Such a wall may be more resistant to shrinkage due to organic contaminants due to the lesser degree of hydration.

While cleaning contaminants from the system, operators held the jetting beam in place at ground level and jetted with water. This produced 6- to 8-ft-deep holes under the jet areas. One or more of these areas connected to a rodent hole in the Sacramento levee, allowing a flow of 40 to 60 gpm to flow from the toe of the levee. Upon switching over to the normal grout slurry and starting to stroke the SoilSaw™, this flow sealed off within less than 1 min due to the high viscosity and thixotropic properties of the soil/grout slurry mixture. Fluidized material in the trench is generally too viscous to flow into cracks or natural fractures. It is expected that the system would perform similarly when encountering a hole or blowout in a real levee.

The D-9 machine is an effective tool and probably has sufficient power to form a wall to the 80- to 100-ft depth range. To reach this depth will require adding the necessary length to the jetting beam, and using a third pumping unit for higher pumping pressures to accommodate more jets at 13-ft spacings or moving up to 20 ft between jet spacings and using the same number of jets. Productivity improvements are possible by fine tuning the jet pattern to be more suited to hard soil formations. This will also help keep grout slurry use to a minimum in forming the wall.

8 Conclusions

General

The SoilSaw™ Barrier System is a workable means of placing barrier walls in soils ranging from 0.5 to 4 tsf at depths to at least 50 ft. The performance of the system is affected dramatically by soil density and strength. The jet pattern and energy levels which worked well in loose to medium compacted sand at the Rush Springs test site did not work well in the unexpectedly stiff fine-grained soils encountered at the Sacramento CPAR test site. The jetting beam did not cut the soil well enough to reach the planned operating depth. During the third test (Palestine) it became apparent that the Gradall platform did not have enough power to stroke the jetting beam in clay soils. The telescoping boom would typically slow down and stall on the up stroke. The Gradall was capable of stroking about 18,000-lb force at 2 ft/sec. This limited the clay soil operating depth to about 24 ft. The equipment was transferred to a modified CAT D-9 machine capable of stroking the beam at up to a 100,000-lb force at 2 ft/sec. The D-9 machine was later used in clay soil at a depth of 45 ft with no indication of power deficiencies. Theoretical calculations indicate in its present form, using 12-ft sections with 13-ft strokes, the machine should be capable of reaching at least 65 ft and by fabricating new jetting beam sections and increasing the stroke length from 13 to 21 ft, the capability should be extended to reach 100-ft depths in dense sands and stiff fine-grained soils.

The SoilSaw™ Barrier System will work in both noncohesive and cohesive soils, but it clearly works faster and better in soft sands and soft to medium fine-grained soils. Hard soils (very dense sands), rock layers, and cohesive clay (strengths > 4.0 tsf) reduced the production rates by as much as two thirds compared to the loose to medium dense sandy soils. Even at these reduced production rates, the method is still faster and potentially more economical than most slurry wall methods. The field tests demonstrated that traditional soils investigation data may not be sufficient to predict productivity. When performing a standard site soil sampling survey, additional information such as unconfined compressive strength may be beneficial in estimating or predicting SoilSaw™ production rates.

The hourly productivity of the method is significantly higher than conventional methods but its true long-term "up time" is not yet proven on a large

project. The narrow but uniform thickness walls produced by the SoilSaw™ Barrier System serve to reduce the spoils volumes and the cost of materials for barrier walls. In loose noncohesive soils, the SoilSaw™ Barrier System can reduce spoils by as much as 80 percent. In hard cohesive soils, the present system (which is limited by its 5,000 psi transfer hoses) may not reduce the generation of spoils except by its ability to form a narrower wall than conventional methods. However, using more jetting horsepower increases production rates and it appears likely that using higher operating pressures in dense or stiff soils should decrease spoils production. The SoilSaw™ has the potential to produce lower cost barriers than conventional methods, although the cost of the method and its maximum depth capability were not established due to the limited "up" time of the system and the very brief field time permitted by the project budget. A full mobilization of the system would include at least a week of planned trouble shooting once the system is assembled. Full operation of the system should be planned to include 2 hr of preparation each day and 1 hr of clean-up each evening and about 5 hr of productive work each day.

Quality of walls produced by this method appears to be excellent, offering clear advantages in loose to medium dense sands overcoming the tendency of the soil to slough off into conventional slurry trenches. The mixing of soil and slurry in place produces a wall material from the start of construction that has a density large enough to prevent sloughing. The system also can work with many different types of slurry materials to obtain construction densities.

Walls are uniformly 12 in. wide with smooth sides using the current jet block design. A new design of jetting nozzle layout, with multiangled jets, may be needed to enhance cutting performance in cohesive soil. It is also possible to add jetting blocks to the beam which will form different width walls or walls with rough sides. Specifying walls more than 12 in. wide increases the cost significantly. Also certain slurry wall specifications, such as those requiring surface mixing of backfill, are inappropriate since the material is mixed in situ.

The SoilSaw™ Barrier System can produce barrier walls, through correct slurry design, that meet or exceed permeability performance standards. Due to a minimum length of wall actually completed on the CPAR site, only a minimum number of permeability tests could be completed and the data are not conclusive for defining final permeability for a production wall. The laboratory permeability values were approximately 10^{-7} , 10^{-7} , 10^{-6} , and 10^{-5} cm/sec for the bulk, block, undisturbed, and tube samples, respectively. A larger number of samples would be needed to verify production permeability. Differences are also related to the difference in field versus laboratory saturation where bulk samples should be close to saturation and tube and block samples are partially saturated for this site.

Advantages of the SoilSaw™ Method

The energy to cut and mix the soil is transferred to the soil work face hydraulically by the reagent media itself. Massive energy transfer of up to 2,000 hydraulic horsepower can be supplied by oil field cement pumps to help achieve dramatic productivity rates up to 10 times faster than conventional methods.

The method forms a very uniform barrier wall with smooth sides and a homogeneous interior.

Barriers can be made thinner, thus reducing spoils disposal cost and raw materials cost while increasing the walls lateral flexibility for any given material.

Barrier walls can be formed in soft wet sands or other unconsolidated formations without sloughing of the formation soils or rocks into the wall because the wall material is as dense as the soils and exerts a balanced hydrostatic force against the soil.

Long barriers can be formed to great depths at a potentially lower cost than other methods.

The continuity of the barrier is assured since the cutting hardware passes through 100 percent of the volume of the wall.

Fluidized material in the "trench" is generally too viscous to flow into cracks or natural fractures.

If pipelines or other underground structures must be tied in to the barrier wall, the SoilSaw™ Barrier System equipment can be used to support jet grouting of the tie-in.

The system can operate on long narrow right of ways, such as levees, with slurry batch plants delivering slurry through a pipeline.

Disadvantages of the Method

The method has a high mobilization cost for the first day of work, therefore, it may only be comparable economically with tracked backhoes on projects specifying a minimum of >1,000 ft long × 30 ft deep and in loose sands. The economics of other sites would depend on type of soil (dense to very dense sands or stiff to hard cohesive soils), depths (up to 100 ft), and special conditions including narrow right-of-ways, spoils management, trench stability, and contaminated groundwater.

The method's production efficiency is greatly reduced in hard cohesive soils (> 4.0 tsf) and is unsuitable for rock or shale.

The method may not be able to "key" into hard rock layers. The nose of the jetting beam can jet scour and bond the wall to a hard rock formation but it would not be able to cut a 3-ft-deep "key" into a hard rock without a significant loss of soil cutting efficiency.

Large rocks, more than 2 ft in diameter, may have to be removed by conventional means. To date, no loose rocks have been encountered which affected normal operation, but it is anticipated that large hard rocks which are able to resist the crushing action of the jetting beam blade could be a problem. This estimate is based on the available stroking force and jetting beam weight.

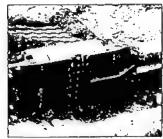
9 Commercialization of the Product

As part of the CPAR-CRDA, commercialization and/or technology transfer was to be performed on a best-effort basis by the partners. The CE has made presentations on the SoilSaw™ technology to the REMR Field Review Group (50 CE attendees) and the International American Public Works Convention (over 50 industry representatives). Numerous mailings of a brochure prepared by the industry partner, Figure 15, have gone to academia and other Federal agencies. A minimum of 400 copies of this report will be mailed to USACE and Federal agency personnel, to libraries, and to academia thus completing the CE obligations in the CPAR-CRDA.

The Halliburton Company, parent company of Halliburton NUS Environmental, has restructured some of its environmental work, and the SoilSaw™ technology is now a program under Brown and Root Environmental, another Halliburton company. Presently, the SoilSaw™ commercialization plan is divided into two phases. The first stage of the commercialization process of the SoilSaw™ is to confirm that it meets client needs and is economically viable. Progressing through this stage requires establishing both performance and cost data for the SoilSaw™ process on a variety of sites with different soil types and different performance specifications. To accomplish these objectives under real world operating conditions, Brown and Root Environmental has established an Industrial Partners for Technology Development Program. The goal of the program is to identify projects and arrive at commercial conditions where use of the SoilSaw™ Barrier System will be mutually beneficial.

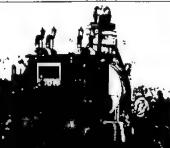
Brown and Root Environmental has solicited a minimum of 10 companies to participate in our program. The program is selectively offered to industrial clients having a good relationship with Brown and Root and a long-term interest in applying the SoilSaw™ to meet their environmental objectives. If clear benefits to both parties exist, the agreements are signed and the SoilSaw™ is used to construct subsurface barriers at the client's site. At least three jobs under Phase 1 should be completed by September 1995.

Brown & Root Environmental has designed the SoilSaw Barrier System to save time in creating strong, underground cutoff walls without conventional excavation or back-filling. The system consists of a heavy pipe, called a "beam," mounted on a specially modified, tracked excavator. The beam is equipped with a high-pressure fluid conduit which terminates in multiple jets placed at regular intervals down the length of the beam.

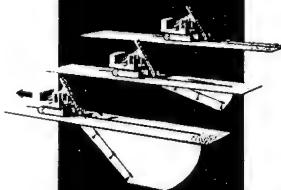


The design incorporates Halliburton high-pressure pumps to accelerate a specially blended cement/bentonite slurry to a very high kinetic energy through these jets. The high-velocity slurry impacts the soil, disturbing the soil structure and creating an intimate blend of soil and slurry to form the in situ wall.

A major benefit of the SoilSaw system is that it requires no excavation. This eliminates the need for expensive treatment and disposal when working in contaminated soil.



*How the system works.
In operation, the beam reciprocates as the cement slurry is pumped through the beam's jetting nozzles. This combined action liquifies the soil so the beam sinks into the ground, functioning as a saw that cuts into the soil along the beam's entire length. As the beam descends to the proper cutting angle, the tracked vehicle begins moving at a rate that is constantly monitored and adjusted to maintain the optimum angle. As the tracked vehicle moves along the ground, gravity*



*pulls the saw against the cutting face in the direction of travel.
Brown & Root Environmental has automated both the beam's reciprocation and the travel of the tracked vehicle to optimize operator and system performance. The operator can make minor course corrections or shut off the automatic mode when required.*

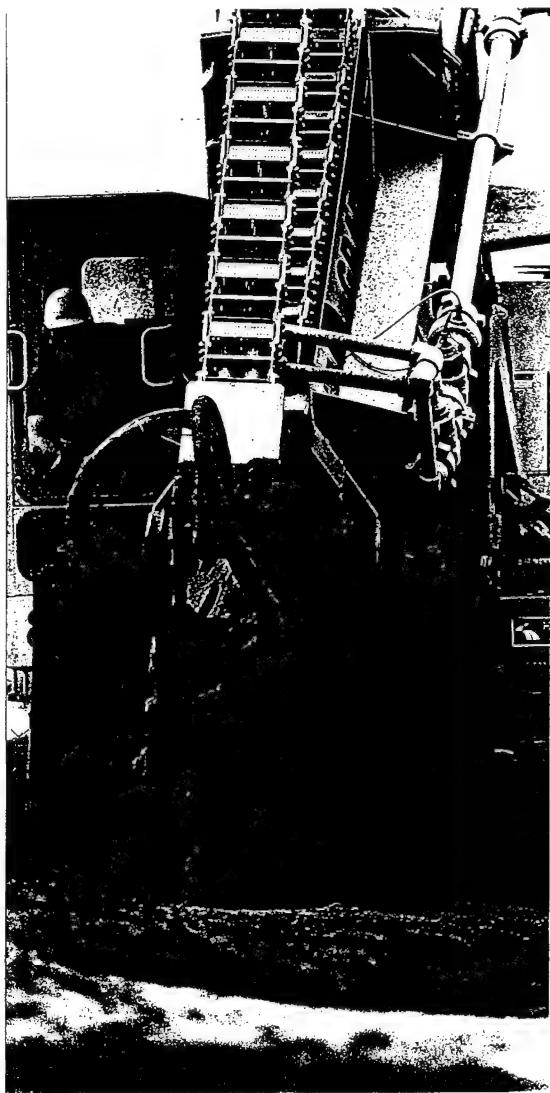


Figure 15. Commercial brochure for SoilSaw™ Barrier System (Continued)

Kinetic energy places the barrier where you want it.

The SoilSaw System does not inject pressurized slurry into the soil, nor does it use mechanical energy to form a trench. The horsepower to form the wall is transferred to the underground workforce by means of the potential energy of the high-pressure fluid inside the beam. All of this pressure is converted to kinetic energy of velocity as it accelerates through the jets into the soil.

Once the slurry contacts the soil, it is incapable of conveying any pressure to the walls of the slurry/soil "trench" other than that due to the hydrostatic head of the column of fluid in the ground. This feature makes the system ideal for reinforcing structures such as earthen levees that cannot tolerate excessive internal pressures.

Secure containment in a wide range of soils.

The SoilSaw System presents a way of installing continuous, deep cutoff walls by transferring energy efficiently to the underground workforce. The process instantly converts undisturbed soil into a viscous, mortar-like material of a precise depth and wall width in a single step. The density of this mortar-like material is equal to or greater than the density of the soil. This reduces the possibility of unprocessed material sloughing off the "trench" sides and compromising the integrity of the cutoff wall.

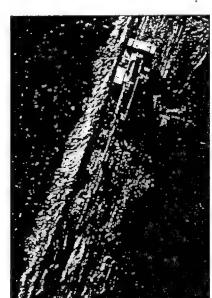
Testing has shown that the system greatly surpasses conventional cutoff wall construction methods in sandy, silty soils. The controlled jetting/cutting action, and the fact that the trench is never empty, contribute to the system's high efficiency in these difficult soil conditions.

The SoilSaw Barrier System is designed for any situation requiring the rapid installation of cutoff walls or in civil engineering projects, such as levee reinforcement, provided there are no massive surface or subsurface obstructions. In those situations, however, Brown & Root Environmental's

In Situ Blender 6™ Soil Mixing System or jet grouting technologies may be applicable.

Proven capabilities under difficult conditions.

During field tests, the SoilSaw Barrier System has proven itself in a sand-like soil specifically selected to simulate the worst-case soil conditions for barrier wall construction. The unit sustained production rates of more than three linear feet per minute, forming a wall one foot wide and 32 feet deep. Slurry mixtures which meet or exceed the Corps of Engineers' specifications for



cutoff walls have been developed for use with the system. The technology has successfully proven the ability to produce a higher-quality cutoff wall in a fraction of the time required by conventional methods. Surface support equipment and personnel requirements are greatly reduced compared to traditional techniques.

Partnering: The next step.

The SoilSaw System has advanced from research and development to the commercialization stage, following a series of tests funded by the Corps of Engineers and the Department of Energy. Brown & Root Environmental is now soliciting industry partners to continue the system's development and commercialization.

THE SOILSAW™ BARRIER SYSTEM: DESIGNED TO CUT TIME AND COSTS ON REMEDIATION AND ENGINEERING PROJECTS.

Brown & Root Environmental

 A Halliburton Company

10200 Bellaire Blvd. / Houston, TX 77072-5299

Phone: 713-575-3000 / Fax: 713-575-4537

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Figure 15. (Concluded)

The second phase of commercialization is fixed-price bidding for commercial barrier construction. Brown and Root Environmental expects to compete the SoilSaw™ for commercial work in 1995. For further information, contact:

Brown and Root Environmental
P.O Box 3
Houston, TX 77001-0003

Brown and Root Environmental
4100 Clinton Drive
Houston, TX 77020

or:

Mr. Kent Saugier, Ph: (713) 676-5283
Mr. Roy Issac, Ph: (713) 676-5280

Appendix A

Drilling, Soil Sampling, and

Laboratory Testing of the

Material in the "SoilSaw" Slurry

Wall Test Section at the Corps'

Disposal Site, West

Sacramento, California



Wahler Associates

Geotechnical and Environmental Engineers

April 13, 1993
Project COE-263T

U.S. Army Corps of Engineers
Sacramento District
Valley Resident Office
P.O. Box 935
West Sacramento, California 95691

Attention: Mr. John L. Sisley, Project Engineer

Subject: Drilling, Soil Sampling and Laboratory Testing
of the Material in the "Soil-Saw" Slurry Wall
Test Section at the Corps' Dredge Disposal Site
West Sacramento, California

Gentlemen:

This report describes the field exploration program conducted along the subject slurry wall test section located west of South River Road in Sacramento, California (see Figure 1), and the subsequent laboratory testing of the sampled material from the slurry wall.

The scope of work was described in our proposal dated March 11, 1993, in accordance with the Corps' revised testing requirements described in their memorandum of March 11, 1993. The work was to consist of drilling and sampling a total of seven (7) borings in and adjacent to the slurry wall test section, and conducting laboratory permeability tests and unconfined compression tests on wet bulk samples and selected undisturbed samples of the slurry wall material.

The wet bulk samples were taken by the Corps, and provided to Wahler for laboratory testing in 2.5-inch diameter plastic molds marked with the appropriate identification. The identification on the samples indicated Stations 0+50 and 2+50, however, it should be pointed out that we were told in the field, by representatives of the Corps,

that the end of the slurry wall was at Station 2+30. This appeared to be in agreement with the Contractor's station markers. Thus, the identification of the sample from Station 2+50 may not be correct.

1.0 FIELD INVESTIGATION

1.1 Procedure

The drilling activities were performed on March 12 and 13, 1993. The borings were drilled using a CME-650 all-terrain drill rig provided by the All Terrain Drilling Company of Santa Rosa, California, under a subcontract to Wahler Associates. All Terrain Drilling Company also provided a tire-mounted backhoe which was used to clear slurry cuttings from each drill site and to locate the slurry wall, prior to drilling.

A total of eight (8) exploratory borings were drilled and sampled at locations identified in the field by Mr. Leo Santa Cruz, of the Corps of Engineers Valley Resident Office (see Figure 2). Table 1 summarizes the boring number, station and purpose of each boring. The borings located in the slurry wall (B-1, B-2, B-3, and B-4, 4A) were generally advanced by hollow-stem augers. However, the slurry wall material in Boring B-4, at Station 00+55, was too hard to advance the boring to its full depth with augers or to obtain the prescribed Shelby tube samples by pushing. Therefore, the drill rig was moved about two feet west, to Station 57+00, and a companion hole, boring B-4A, was advanced using rotary wash drilling. Undisturbed Shelby tube samples were cored in boring B-4A with a Pitcher barrel sampler at the prescribed depths. Shelby tube samples of the slurry wall were also obtained from boring B-3, at Station 25+00. At this location, the wall was soft enough to obtain the samples by pushing the Shelby tubes. The undisturbed Shelby tube samples taken in Borings B-3 and B-4 were taken in two-foot intervals between the depths of 8 and 12 feet below the ground surface.

Borings B-5 and B-6; at Stations 0+00 and 0+25, respectively, were advanced by continuous driving of the SPT sampler. Boring B-7, at Station 2+10, was advanced by nearly continuous SPT sampling, except that after sampling to a depth of 13.5 feet, the



April 13, 1993

Page 3

hole was cleaned out with the augers to a depth of about 14 feet prior to commencing SPT sampling again to a total depth of 21.5 feet.

Preliminary visual soil classifications were made in the field in accordance with ASTM Standard Method Designation D2488-84 and were verified by further inspection of the samples in our laboratory. Boring logs were prepared in the field and are included with this letter report.

The Shelby tube samples were sealed in the field using plastic caps and tape to prevent loss of moisture. The samples were then carefully packed in wooden crates, padded with foam rubber and transported to our Palo Alto soils laboratory.

After the drilling activities were completed, the borings were backfilled with drill cuttings. All remaining soil cuttings were left on the levee crown.

1.2 Subsurface Conditions

The following section provides a summary of the materials encountered in the borings within and adjacent to the slurry wall.

1.2.1 Slurry Wall Material - In general, the slurry wall material consisted of dark olive-grey sandy silt (by the Unified Soil Classification System). The slurry material had a soil-cement consistency with no visible mass chunks or lenses of cement or native soil, and appeared to be well-mixed, as noted by its uniform coloring and composition.

At Stations 00+00, 00+25 and 02+10, the slurry material was soft, weakly cemented and very moist to wet, as noted by the ease of Shelby tube penetration and/or the relatively low SPT blowcounts. At Stations 00+55 and 00+57, the slurry material was hard and moderately cemented below a depth of about 11 feet.

The base of the slurry wall was easily identified in the borings and typically consisted of a horizontal contact between the dark olive-grey slurry material above and undisturbed yellowish-brown silt and sand levee material below. In several borings,



Wahler Associates

pockets of slurry material were encountered 1 to 2 feet below the bottom of the slurry wall.

1.2.2 Levee Materials - At the locations drilled, the levee was comprised of silt, with some fine-grained sands. The upper 2 feet of the levee consisted of a layer of loose, fine-grained sand. Below this surface layer, the levee materials consisted primarily of stiff to very stiff, dark yellowish-brown sandy silt with mixed layers of medium-dense fine-grained sand and silty sand. Native material was apparently encountered at depths of between 19 and 22 feet below the levee crown, and consisted of stiff silt and medium dense silty sand.

2.0 LABORATORY TESTING

The laboratory testing consisted of performing 2 constant head permeability tests and 2 unconfined compression tests on selected undisturbed samples from the borings, and 2 constant head permeability tests and 2 unconfined compression tests from the wet bulk samples collected by the Corps. At the Corps' request, the tests were to be performed at a cured age of as close to 28 days after installation as possible.

One permeability test was performed on each boring from a sample depth of about 10 feet. Specimens for testing were initially selected based on criteria of depth and minimum disturbance, as indicated from the descriptions on the boring logs. After cutting and extruding the selected sample, and based on visual evaluation, only very high quality specimens were used for testing. If a specimen was of questionable quality, then another section was cut and extruded until a high quality sample was obtained. Permeability testing was performed on March 30 and April 1, 1993.

One unconfined compression test was performed on an undisturbed sample from each boring. The criterion for selection of samples was to obtain the best quality specimen from the samples remaining after the permeability testing. Therefore, most of the remaining samples were cut and extruded, and the best available specimen was selected for testing. One unconfined compression test was performed on one specimen from



each set of wet bulk samples. The unconfined compression tests were performed on March 31, 1993 and April 1, 1993.

2.1 Permeability Testing

2.1.1 Sample Preparation - In order to minimize sample disturbance, the sample tubes chosen for sample preparation were cut into smaller sections using a radial pipe cutter.

The sections chosen for sample preparation were extruded using a hydraulically-operated ram cable exerting the minimum force necessary to free the sample from the tube. The samples were extruded from the tube so that they traveled in the same direction as when they were sampled, again minimizing disturbance. The samples were then trimmed to a height of approximately 4 inches. With the aid of a special trimming device which completely supported the sample, the possibility of sample disturbance due to handling was significantly reduced.

After the initial weight and volume measurements were determined, each specimen was placed in a triaxial cell, encased in a latex membrane and sealed to the bottom pedestal and top cap with rubber "O" rings. Both the bottom pedestal and top cap are fitted with porous stones which have permeabilities estimated to be at least 3 orders of magnitude greater than the samples tested. After securing the triaxial chamber, the cell was filled with water and transported to the saturation bay.

2.1.2 Sample Saturation and Consolidation - The laboratory is equipped with a panel of nine bays, with an individual pressure control to each bay, such that nine triaxial samples can be simultaneously saturated and/or consolidated at different individual pressures. Bleeding air regulators capable of delivering air pressure up to 140 psi are used to control the top, bottom, and chamber lines leading to the triaxial cells. Each saturation bay is also equipped with constant diameter Pyrex sight tubes, each with a cross-sectional area of 0.075 square inch, which connect with the base of the triaxial cell, and thus to the sample. The sight tubes are easily read to the nearest 0.01 cubic inch.



The samples were saturated using a combination vacuum-back pressure technique. A small vacuum was applied to the top and bottom sample lines to remove air trapped in the lines and to increase the initial saturation without a change in void ratio. A pressure of 70 psi was then incrementally applied to both the top and bottom sample pore fluid lines and the triaxial chamber to obtain a sufficient degree of saturation prior to the consolidation phase of the test. This increase in pore pressure and confining pressure forces air trapped in the sample and lines to be dissolved into solution, but results in no net stress application to the sample. In order to determine whether the back pressure applied was causing complete saturation, Skempton's "B" parameter was measured for all samples. A value in excess of 0.95 was considered to represent a fully saturated condition. After achieving complete saturation, the chamber pressure was increased to 10 psi above the sample fluid pressure, giving the samples a net effective stress of 10 psi. This stress level is approximately equivalent to the stress level of the samples as they cured in the wall prior to sampling. The top and bottom drainage lines were then simultaneously opened, and the total volume of water expelled from each sample was monitored.

2.1.3 Permeability Test Results - The permeability was determined by applying a constant pressure head of 2.3 feet (equal to a pressure of 1 psi) to the sample and monitoring the flow of water from bottom to top of the sample as a function of time, using calibrated, constant diameter sight tubes. The permeability test results are summarized in Table 2. The tests were run several times to confirm that permeability did not vary appreciably with time.

2.2 Unconfined Compression Testing

Selected samples were tested for unconfined compressive strength in accordance with ASTM D2166-91. Sample extrusion and trimming was performed as described for the permeability test, except that the specimens were trimmed to an approximate 2:1 height



Table 12
Mix Design

Slurry No.	Bentonite Concentration	Density No./Gal	Cement Concentration	Flyash Concentration	Additive No. 1	Additive No. 2	Remarks
1	22 lb/bbl				2.9 lb/bbl		
2	22 lb/bbl		100 lb/bbl		2.9 lb/bbl		Additive No. 1 Lignosite
3	22 lb/bbl		100 lb/bbl	295 lb/bbl c/b		.68 lb/bbl	Class F flyash Additive No. 2 CFR-3

U.S. Army Engineer District, Sacramento

April 13, 1993

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to diameter ratio. Strength and axial strain were monitored during the tests. A summary of the test results is presented in Table 3.

We are pleased to have had the opportunity to provide these services to the Corps. If you have any questions regarding the content of this report, or if we can be of any further assistance, please do not hesitate to call.

Very truly yours,

WAHLER ASSOCIATES



Michael R. Mooers
Principal Engineer

JM:geo/rep



Wahler Associates

TABLE 1
BORING SUMMARY

Boring No.	Station	Purpose
B-1 B-2	0+00 2+10	Borings drilled into the slurry wall to determine the depth of the wall.
B-3 B-4* B-4A*	0+25 0+55 0+57	Borings drilled into the slurry wall to obtain undisturbed samples of the wall for laboratory testing.
B-5 B-6 B-7	0+00 0+25 2+10	Borings drilled adjacent to the slurry wall to perform continuous SPT in the levee material for soil identification.

*The slurry wall material in Boring B-4 was too hard to push Shelby tubes. Therefore, the drill rig was moved 2 feet west and boring B-4A was redrilled with rotary wash drilling. Shelby tube samples were cored with the Pitcher barrel sampler.



TABLE 2

**SUMMARY OF "SOIL-SAW" SLURRY
WALL TEST SECTIONS
PERMEABILITY TEST RESULTS**

Station	Depth (ft)	Type of Sample	Date Wall Installed	Date Sample Taken	Date Sample Transported	Age During Test (Days)	Initial		As-Tested		Coefficient of Permeability (cm/sec)		
							Water Content (%)	Dry Density (pcf)	Water Content (%)	Dry Density (pcf)			
00+25	8-10	Undist.	3/3/93*	3/12/93	3/13/93	3/30/93	27	47.5	70.4	49.0	70.8	7.0	1.2x10 ⁻⁶
00+50	13	Bulk	3/3/93	3/3/93	3/13/93	3/30/93	27	41.8	76.6	43.4	77.2	7.5	9.0x10 ⁻⁸
00+57	8-10	Undist.	3/3/93	3/13/93	3/13/93	4/1/93	29	42.5	76.4	44.3	76.7	7.3	1.7X10 ⁻⁶
2+50	15	Bulk	3/4/93	3/13/93	4/1/93	4/1/93	28	59.6	64.0	59.4	64.4	7.8	4.0x10 ⁻⁷

*Assumed

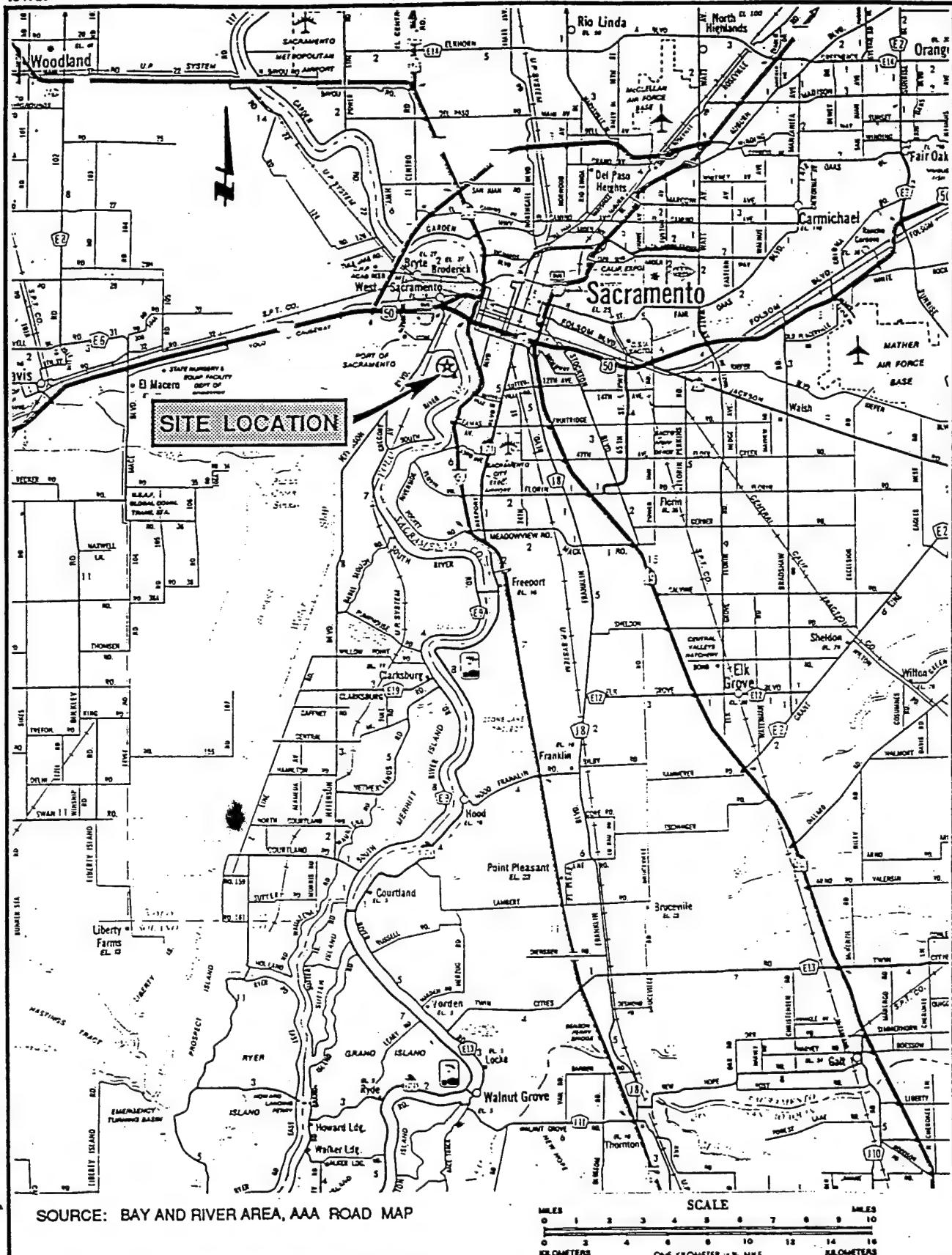
TABLE 3

**SUMMARY OF "SOIL-SAW" SLURRY
WALL TEST SECTIONS
UNCONFINED COMPRESSIVE STRENGTH
TEST RESULTS**

Station	Depth (ft)	Type of Sample	Date Wall Installed	Date Sample Taken	Date Sample Transported	Date Sample Tested	Age During Test (Days)	Water Content (%)	Dry Density (pcf)	Peak Unconfined Compressive Strength (psi)
00+25	8-10	Undist.	3/3/93*	3/12/93	3/13/93	3/31/93	28	49.5	68.3	14.8 @ 2.9%
00+50	13	Bulk	3/3/93	3/3/93	3/13/93	3/31/93	28	43.4	75.4	32.9 @ 3.0%
00+57	8-10	Undist.	3/3/93	3/13/93	3/13/93	3/31/93	28	42.0	76.2	53.3 @ 2.7%
2+50	15	Bulk	3/4/93	3/4/93	3/13/93	4/1/93	28	59.5	64.2	22.6 @ 4.0%

*Assumed

134729



SOURCE: BAY AND RIVER AREA, AAA ROAD MAP

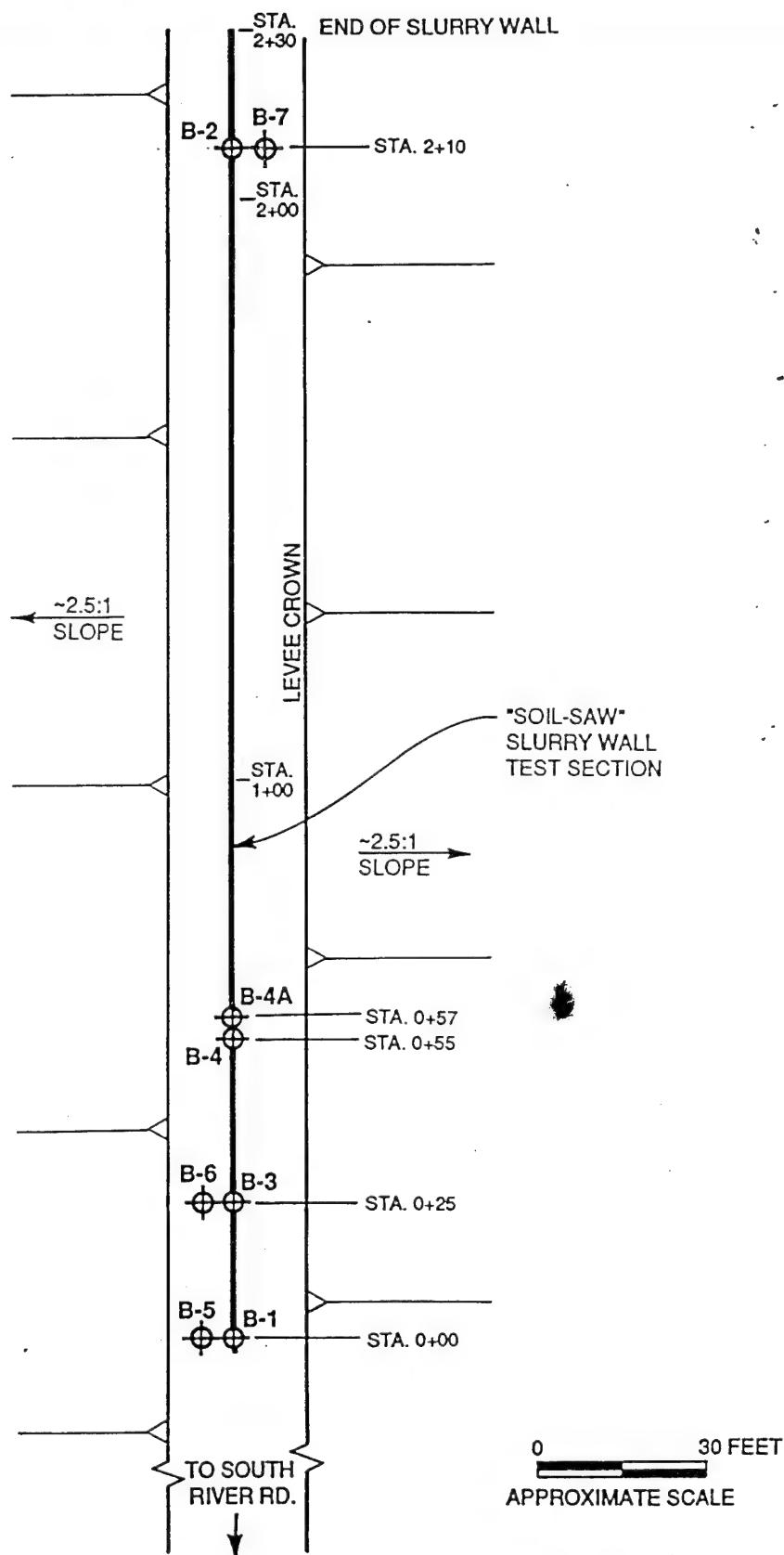
W Wahler
Associates

**"SOIL-SAW" SLURRY WALL
TEST SECTION
U.S. CORP OF ENGINEERS**

PALO ALTO • CALIFORNIA

LOCATION MAP

PROJECT NO.	DATE	FIGURE NO.
COE-263T	APRIL 1993	1



BORING LOCATION Centerline of Slurry Wall; Station 2+10.				GROUND EL.		
DEPTH/ELEV. WATER NE DRILL CONTRACTOR AID.				TOTAL DEPTH 24'		
DRILL RIG CME 65D	BORING DIA. 6"	DATE DRILLED 3/13/93		LOGGED BY JM		
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD	REC.	MODE
MV	<u>SLURRY WALL</u> 0-19': sandy silt; dark olive grey; moist to very moist; appears soft; est ~10% very fine sand; very faint cemented dots; some mixed clumps of dark brown silt to 14'.	0				HA
SLURRY WALL	12-19' as above; increase sand; ~20-30% very fine sand; drier; moist to s. moist; crumbly & brittle	2				
		4				
		6		1/2 2 2 2	2.0 2.0	DR
		8				HA
		10				
		12				12-14' SPT
		14	B-1	2/3 4 7	2.0 2.0	DR
		16		2/4 7 10	2.0 2.0	DR
		18	B-2	3/5 7 10	2.0 2.0	DR
		20		4/12 16 19	2.0 2.0	DR
SM	<u>LEVEE MATERIAL</u> 19'-22': SILTY SAND; dark yellowish brown w/orange layering; damp; medium dense; fine grained; est ~10-30% silt; some silt layers; 21'.					
Wahler Associates				EXPLORATION BORING LOG		BORING NO.
"SOIL-SAW" SLURRY WALL TEST SECTION U.S. CORPS OF ENGINEERS				PROJECT NO.	SHEET NO.	
				COE-263T	1 OF 2	B-2

BORING LOCATION				GROUND EL.			
DEPTH/ELEV. WATER		DRILL CONTRACTOR			TOTAL DEPTH		
DRILL RIG		BORING DIA.		DATE DRILLED			LOGGED BY
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD	REC.	MODE	REMARKS
ML (SLURRY)	② 20'-21.5': sandy silt slurry mix as at 0-19'.	20	—	5 6 15 16	2.0 2.0	DR	20-22' SPT
SM	③ 21.5' silty sand as at 19' NATIVE MATERIAL (?)	21	—	4 4 5 5	2.0 2.0	DR	22-24' SPT
Mt	22-24': T(2) CLAYEY SILT dark brown and mottled orange moist; stiff trace very fine sand.	22	—	4 4 5 5	2.0 2.0	DR	10:45 AM
	TD = 24'	24	—	—	—	—	Terminate boring.

EXPLORATION DRILL HOLE LOG
DISCLAIMER

DATA ON THIS LOG ARE AN APPROXIMATION OF THE GEOLOGIC AND SURFACE CONDITIONS BECAUSE THE INFORMATION WAS OBTAINED FROM INDIRECT, DISCONTINUOUS, AND POSSIBLY DISTURBED SAMPLING NECESSITATED BY USE OF SMALL-DIAMETER HOLES. ROTARY AND WASH DRILLING HOLES HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASING IN ADVANCING HOLES.

THIS LOG INDICATES CONDITIONS IN THIS HOLE ONLY ON THE DATE INDICATED AND MAY NOT REPRESENT CONDITIONS AT OTHER LOCATIONS AND ON OTHER DATES. ANY WATER LEVELS SHOWN ARE SUBJECT TO VARIATION.

THE HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.

THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN MATERIAL TYPES, AND THE TRANSITIONS MAY BE GRADUAL.

SOIL CLASSIFICATIONS SHOWN ON LOGS ARE FIELD CLASSIFICATIONS BASED ON THE UNIFIED SOILS CLASSIFICATION SYSTEM.

BORING LOCATION Centerline of Slurry Wall STATION 00+25.						GROUND EL. —	
DEPTH/ELEV. WATER	Not Encountered	DRILL CONTRACTOR All Terrain Drilling			TOTAL DEPTH 16'		
DRILL RIG CME 650	BORING DIA. 8"	DATE DRILLED 3/12/93		LOGGED BY JM			
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD	REC.	MODE	
	SLURRY WALL	0				1:30pm	
ML	0'-12.5': SANDY SILT; dark olive grey; wet; appears soft; some very fine sand; weakly cemented. Faint cement odor; appear uniformly mixed.	2			HA	Advance hole w/B" auger.	
SLURRY WALL	② 5'-6.5' SANDY SILT (slurry) as above; est 10-15% vfg sandy; very moist; some dark brown silt clumps.	6	Rod weight 1	1.5 1.5	DR	DATA ON THIS LOG ARE AN APPROXIMATION OF THE GEOLOGIC AND SUBSURFACE CONDITIONS BECAUSE THE INFORMATION WAS OBTAINED FROM INDIRECT, BORING, AND POSSIBLY DISTURBED SAMPLING, NECESSITATED BY USE OF SMALL-DIAMETER HOLES. SLANT AND VANE BORING HOLE HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASING IN ADVANCING HOLES.	
ML	③ 8'-10': as above. <small>(possibly at 9.5')</small>	8	S-1	1100 psi	2.0 2.0	P	THIS LOG INDICATES CONDITIONS IN THIS HOLE ONLY ON THE DATE INDICATED AND MAY NOT REPRESENT CONDITIONS AT OTHER LOCATIONS AND ON OTHER DATES. ANY WATER LEVELS SHOWN ARE SUBJECT TO VARIATION.
	④ 10'-12': as above. ⑤ 12.5': Bottom of slurry wall; horizontal contact with levee materials.	10	S-2	1100 psi	2.0 2.0	P	THIS HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.
ML	LEVEE MATERIAL 12.5'-15': SANDY SILT drk yll brn and dark olive grey; s. moist, stiff (low pl) est 10-20% vfg sandy; crumbly friable; some mixed sandy pellets	12	B-1	4 5 8 11	2.0 2.0	DR	8-10' Push 3" x 36", shelby tube, slurry material is soft easily penetrated. No pull down reading on rig gage. 10-12' Push
SM-M2	⑥ 14.5': isolated pocket of SANDY SILT SLURRY MATERIAL at 15' - grades to sandy silt; dark yll brn w/mixed grey brown s. moist vfg sand; 30-50% non pl silt; some roots and organic detritus.	14	B-2	4 5 6 9	2.0 2.0	DR	12-14' SPT
	TD=16.0'	16					14-16' SPT
		18					2:20pm
Wahler Associates	SOIL-SAW SLURRY WALL TEST SECTION U.S. CORPS OF ENGINEERS	EXPLORATION BORING LOG			BORING NO. B-3		
		PROJECT NO. COE-263T	SHEET NO. 1 OF 1				

BORING LOCATION	Centerline of Slurry Wall; STATION 00+55	GROUND EL.					
DEPTH/ELEV. WATER	Not Encountered.	TOTAL DEPTH 17.2'					
DRILL RIG CME-650	BORING DIA. 8"	LOGGED BY JM					
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD	REC.	MODE	REMARKS
ML	SLURRY WALL 0'-13.9': SAVOY SILT; dark olive grey, very moist to wet; appears soft; some very fine sand; weakly cemented; faint cement odor.	0					Advance boring with 8" HSA. -soft remolded cuttings.
SLURRY WALL		2				HA	
MR W/SM		4					
		6	B-1	1/2	1.5 1.5	DR	5-6.5' SPT
		8				HA	
		10		100 psi	0.0 2.0	P	8-10' Push 3" x 36" shelby tube, sample lost on retrieval. drill to 10'
		12	S-1	+250 psi	1.2 1.0	P	10-11.2' Push shelby tube from 10 to 11' 0 psi pull down at 11' material harder +250 psi - refusal.
		14	B-1	8 12 18 24	2.0 2.0	DN	11.2-13.2 - SPT
	LEVEE MATERIAL	16		10 13 12 11	2.0 2.0	DR	13.2-15.2 SPT
	13.9'-17.2': SAVOY SILT; mottled olive grey brown and dark yellowish brown; very stiff; est. 20-30% very fine sand; some sandy layers; crumbly.	18		4 4 6 7	2.0 2.0	DN	15.2-17.2' SPT
	TD = 17.2'.	20					5:00pm Terminate boring will move hole forward to STATION 00+57 and recover shelby samples.

 Wahler
Associates

"SOIL-SAW" SLURRY WALL
TEST SECTION
U.S. CORPS OF ENGINEERS

EXPLORATION BORING LOG

PROJECT NO.

COE-263T

SHEET NO.
1 OF 1

BORING NO.

B-4

BORING LOCATION Center line of Slurry Wall - station 20+57'						GROUND EL.
DEPTH/ELEV. WATER Not Encountered		DRILL CONTRACTOR ATD.		TOTAL DEPTH 12'		
DRILL RIG CME 650 A		BORING DIA. 8"	DATE DRILLED 3/13/73		LOGGED BY JM	
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR / RQD	REC.	MODE
MH	SLURRY WALL 0'-12' SANDY SILT; dark olive grey; very moist; est 10-15% very fine sand; faint cemented odor.	0				Auger to 4'
<p>DATA ON THIS LOG ARE AN APPROXIMATION OF THE GEOLOGIC AND SUBSURFACE CONDITIONS BECAUSE THE INFORMATION WAS OBTAINED FROM INDIRECT, DISCONTINUOUS, AND POSSIBLY DISTURBED SAMPLING, FACILITATED BY USE OF SMALL-DIAMETER HOLES. ROTARY AND MAST DRILLING HOLES HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASING IN ADVANCING HOLES.</p> <p>THIS LOG INDICATES CONDITIONS IN THIS HOLE ONLY ON THE DATE INDICATED AND MAY NOT REPRESENT CONDITIONS AT OTHER LOCATIONS AND ON OTHER DATES. ANY WATER LEVELS SHOWN ARE SUBJECT TO VARIATION.</p> <p>THIS HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.</p> <p>THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN MATERIAL TYPES, AND THE TRANSITIONS MAY BE GRADUAL.</p> <p>SOIL CLASSIFICATIONS SHOWN ON LOGS ARE FIELD CLASSIFICATIONS BASED ON THE UNIFIED SOILS CLASSIFICATION SYSTEM.</p>						
<p>SLURRY WALL</p> <p>0'-12' SANDY SILT; dark olive grey; very moist; est 10-15% very fine sand; faint cemented odor.</p> <p>TD = 12'</p>						
<p>4-6' Push Shelby to confirm wall. No recovery. Push a 2.5" ID. mod cal sampler to recover.</p> <p>6-8' Pitcher Barrel sample with 3" x 36" shelby tube. 1:30 min run; full water return.</p> <p>8-10': Pb sample 2:00 min run; full water return. Tube slightly scarred on sides.</p> <p>10-12' Pb sample; 3:00 min run; harder drilling at 11'.</p> <p>9:30 AM Terminate boring.</p>						

 Wahler
Associates

"Soil-Saw" SLURRY WALL
TEST SECTION
U.S. CORPS OF ENGINEERS

EXPLORATION BORING LOG
PROJECT NO. CDE 7.63T SHEET NO. 1 OF 1

BORING NO. B-4A

BORING LOCATION STA 0 too 3' south of Slurry Wall							GROUND EL.
DEPTH/ELEV. WATER Not Encountered			DRILL CONTRACTOR ATD			TOTAL DEPTH 16.5	
DRILL RIG CME 650 AT			BORING DIA. 8"		DATE DRILLED 3/12/93		LOGGED BY JM
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD	REC.	MODE	REMARKS
	LEVEE MATERIAL	0		1 1 2	1.5 1.5 1.5	DR	12:00pm
SP	0'-1.2': SAND; yellowish brown; moist, loose; fine grained; some olive grey silt mixed						continuous SPT using 140# autohammer; auger out.
SM-ML	1.2'-2.0': SILTY SAND - SANAY SILT; dark yellowish brn to olive grey; moist; soft; very fine sand; silty; mixed clumps of silt (ML);	2	B-1	1 1 2	1.5 1.5 1.5	DR	3-4.5' SPT
ML	2'-8' SILT - SANAY SILT; grey brown to dark brown; very moist; soft; some roots and organics; occasional sand pockets.	4		2 3 7	1.5 1.5 1.8	DR	4.5-6' SPT
SM	② 3-3.5': SILTY SAND layer.						
ML	③ 3.5': stiffer material; some root layers - occasional sandy pockets 1-3" thick.	6	B-2	4 5 7	1.5 1.5 1.5	DR	6-7.5' SPT
	④ 7.5': decrease moisture to slightly moist						7.5-9' SPT
SM w/ML	8'-9.5' SILTY SAND - mixed w/ SILT) dark yellowish brn mottled grey brown; s. moist; stiff; fine grained; mixed layers of sm w/ h. r. sp.; some root 3.	8	B-3	3 3 6	1.5 1.5 1.5	DR	9-10.5' SPT
ML	9.5'-12.5' SILT - SANAY SILT; as at 2-8'; slightly moist, sandy layers to 1-2". 10.5-12' mostly ML) dark yellowish brown and grey brn; local v. moist zones; some sandy pockets.	10		3 4 10	1.5 1.5 1.5	DR	10.5-12' SPT
SM-ML	12.5'-14': SILTY SAND; dark yellowish brn; s. moist) med. dense; VFG - 30-60% SILT (sm-m); some wood fragments	12	B-4	4 6 10	1.5 1.5 1.5	DR	12-13.5' SPT
ML	⑤ 14': grades to SANAY SILT; dark yellow brn s. moist; stiff; low PL; some layers of SM; est. 10-20% VFG sand; brittle and crumbly.	14		6 9 10	1.5 1.5 1.5	DR	13.5-15' SPT
	TD=16.5.	16	B-5	5 5 9	1.5 1.5 1.5	DR	15-16.5' SPT
		18					12:45
		20					Terminate boring.
<small>DATA ON THIS LOG ARE AN APPROXIMATION OF THE GEOLOGIC AND SUBSURFACE CONDITIONS. BECAUSE THE INFORMATION WAS OBTAINED FROM INDIRECT, DISCONTINUOUS, AND POSSIBLY DISTORTED SAMPLING NECESSITATED BY USE OF SMALL-DIAMETER HOLES, ROTARY AND WASH DRILLING HOLES HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASTING IN ADVANCING CYLINDERS.</small>							
<small>THIS LOG INDICATES CONDITIONS IN THIS HOLE ONLY ON THE DATE INDICATED AND MAY NOT REPRESENT CONDITIONS AT OTHER LOCATIONS OR ON OTHER DATES. ANY WATER LEVELS SHOWN ARE SUBJECT TO VARIATION.</small>							
<small>THIS HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.</small>							
<small>THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN MATERIAL TYPES, AND THE TRANSITIONS MAY BE GRADUAL.</small>							
<small>SOIL CLASSIFICATIONS SHOWN ON LOG ARE FIELD CLASSIFICATIONS BASED ON THE UNIFIED SOILS CLASSIFICATION SYSTEM.</small>							

BORING LOCATION ~3' south of Slurry Wall C't; STATION 00+25				GROUND EL.
DEPTH/ELEV. WATER Not Encountered				TOTAL DEPTH 18'
DRILL RIG CME 650 BORING DIA. 8"				LOGGED BY JM
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR RQD
				REC. MODE
	<u>LEVEE MATERIAL</u>	0		
SP	0-1.3' SANDY med. yll/brown; damp; loose; firm med. grained roots.			1.5 1.5 1.5
ML	1.3'-18': SANDY SILT; dark yellowish brown w/grey brown mottling; moist; est. 10-20% very fine sand; changes noted below:	2	B-1	2 2 1.0 1.5
	① 3-4.5': includes SP layers 2"-3" thick; mtn to v. moist.	4		3 3 1.5 1.5
	② 4.5'-6': moist; decrease sand content.	6	B-2	2 2 1.5 1.5
	③ 6'-7.5': very moist.	8		2 2 1.5 1.5
	④ 7.5'-9': increase sandy; 30-40% silt; some sand layers <1"; moist.	10	B-3	2 2 1.0 1.5
	⑤ 9-10.5': decrease sand; damp; crumbly; some oxidized roots.	12		3 3 1.5 1.5
	⑥ 10.5'-11': increased sand; up to 40% very fine grained sand; slightly moist; crumbly.	14	B-4	4 4 1.0 1.5
SM	⑦ 12.5'-13': SILTY SAND; yllw brn; friable.	16		3 3 1.5 1.5
ML	⑧ 14'-14.5': SILTY SAND layer.	18	B-5	3 3 1.5 1.5
SM	⑨ 15-16.5': some sand layers 1-2" thick.	20		3 3 1.5 1.5
ML	⑩ 17'-17.6': SILTY SAND layer		B-6	4 4 1.5 1.5
	TD = 18'			

DATA ON THIS LOG ARE AN APPROXIMATION OF THE GEOLOGIC AND SUBSURFACE CONDITIONS BECAUSE THE INFORMATION WAS OBTAINED FROM DIRECT, DISCONTINUOUS, AND POSSIBLY DISTURBED SAMPLING NECESSITATED BY USE OF SMALL-DIAMETER HOLES. ROTARY AND WASH BORING HOLES HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASING IN ADVANCING HOLES.

LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.

THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE MATERIAL TYPE, AND THE TRANSITIONS MAY BE GRADUAL.

BORL CLASSIFICATIONS SHOW ON LOG AND FIELD CLASSIFICATION SYSTEM.

THIS HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.

THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE MATERIAL TYPE, AND THE TRANSITIONS MAY BE GRADUAL.

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THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE MATERIAL TYPE, AND THE TRANSITIONS MAY BE GRADUAL.

BORL CLASSIFICATIONS SHOW ON LOG AND FIELD CLASSIFICATION SYSTEM.

ONLY THE DATE INDICATED AND THE DATA REPRESENT CONDITIONS AT OTHER LOCATIONS.

"SAW" SLURRY WALL TEST SECTION

Associates

U.S. CORPS OF ENGINEERS

EXPLORATION BORING LOG

BORING NO.

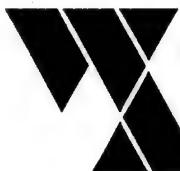
PROJECT NO. SHEET NO.
COE-263T 1 OF 1

B-6

BORING LOCATION							GROUND EL.
DEPTH/ELEV. WATER		DRILL CONTRACTOR					TOTAL DEPTH
DRILL RIG		BORING DIA.	DATE DRILLED			LOGGED BY	
SOIL CLASS.	DESCRIPTION	DEPTH	SAMPLE NO.	PR / RQD	REC.	MODE	REMARKS
SP	21.-21.5': CLAYE/SILT; dark grey brown-orange mottling; moist; very stiff; some fine sand, roots.	20		2 2 10	1.5 1.5	DL	20-21.5' SPT
ML	TD = 21.5'	22					12:15 pm Terminate boring.
<small>DATA ON THIS LOG ARE AN APPROXIMATION. THE GEOLOGIC AND SUBSURFACE CONDITIONS BECAUSE THE INFORMATION WAS OBTAINED FROM LOGGING. DISCONTINUOUS, AND POSSIBLY DISTORTED, DRILLING NECESSITATED BY USE OF SMALL-DIAMETER HOLES. ROTARY AND WALK-THROUGH HOLES HAVE FURTHER COMPLICATIONS IN THIS REGARD BECAUSE OF THE NEED TO USE DRILLING FLUID AND/OR CASING IN ADVANCING HOLES.</small>							
<small>THIS LOG INDICATES CONDITIONS IN THIS HOLE ONLY ON THE DATE INDICATED AND MAY NOT REPRESENT CONDITIONS AT OTHER LOCATIONS AND ON OTHER DATES. ANY WATER LEVELS SHOWN ARE SUBJECT TO VARIATION.</small>							
<small>THIS HOLE WAS LOGGED IN SUCH A WAY AS TO PROVIDE DATA PRIMARILY FOR DESIGN PURPOSES AND NOT NECESSARILY FOR THE PURPOSES OF SPECIFIC CONTRACTORS.</small>							
<small>THE STRATIFICATION LINES OR DEPTH INTERVALS REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN MATERIAL TYPES, AND THE TRANSITIONS MAY BE GRADUAL.</small>							
<small>SOIL CLASSIFICATIONS SHOWN ON LOG ARE FIELD CLASSIFICATIONS BASED ON THE UNIFIED SOILS CLASSIFICATION SYSTEM.</small>							

Appendix B

Observation of Excavation and Sampling and Laboratory Testing of the Previously Formed Soil-Saw Slurry Wall Test Section in West Sacramento, California



Wahler Associates

Geotechnical and Environmental Engineers

January 11, 1994
Project COE-263W

U.S. Army Corps of Engineers
Sacramento District
Valley Resident Office
P.O. Box 935
West Sacramento, California 95691

Attention: Mr. John Sisley
Project Engineer

Subject: Observation of Excavation and Sampling
and Laboratory Testing of the Previously
Formed Soil-Saw Slurry Wall Test Section in
West Sacramento, California

Reference: Report to Corps of Engineers, Valley Resident Office;
*Drilling, Soil Sampling and Laboratory Testing of the
Material in the 'Soil-Saw' Slurry Wall Test Section at
the Corps' Dredge Disposal Site, West Sacramento,
California*", Wahler Associates, April 13, 1993.

Gentlemen:

Enclosed is our report of our observation of excavation, sampling and laboratory testing of the previously formed soil-saw slurry wall test section in West Sacramento, California. We are pleased to have had the opportunity to be of assistance to the Corps. If you have any questions regarding this report, or if we can be of any further assistance, please do not hesitate to call.

Very truly yours,

WAHLER ASSOCIATES

Michael R. Mooers
Principal Engineer

MRM:geo/rep

**OBSERVATION OF EXCAVATION AND SAMPLING
AND LABORATORY TESTING
PREVIOUSLY FORMED SOIL-SAW SLURRY WALL TEST SECTION
CORPS' DREDGE DISPOSAL SITE
WEST SACRAMENTO, CALIFORNIA**

1.0 INTRODUCTION AND BACKGROUND

The subject project consisted of excavation, sampling, and laboratory testing of a previously formed slurry wall test section. The field work was performed from October 26, 1993 to October 28, 1993. The samples obtained were tested in our laboratory between November 4, 1993 and November 17, 1993.

The approximately 250-foot long test section was originally installed in March 1993, in an inactive levee at the Corps of Engineers' Dredge Disposal Site in West Sacramento, California. The test section was constructed by Haliburton, Inc./Brown & Root Environmental, using the experimental "soil-saw" technology.

The "soil-saw" technique discharges slurry mix at very high pressure from a series of nozzles located along a tubular beam. The beam, which is pinned on one end and attached to a backhoe-like tractor, is laid out horizontally on the ground, and sinks into the ground due to a combination of the jetting action of the slurry and the mechanical back-and-forth "sawing" action of the beam itself. The technique results in a mixed-in-place blend of the slurry and the surrounding native soils. Various trial slurry mix designs were used in the construction of the wall. A detailed description of the slurry mix design is contained in the attached memo from Brown & Root Environmental dated November 10, 1993 (Attachment No. 1).

The test wall was constructed for the Corps of Engineers Waterways Experiment Station (WES) of Vicksburg, Mississippi. Mr. Roy Leach, of WES, was project manager for WES, and was on-site in March 1993 during installation of the wall. Mr. Leach was unable to be on-site during this current phase of the project.

The test wall was previously sampled and tested shortly after construction, by Wahler Associates. The referenced report describes the results of that field and laboratory



investigation. The previous laboratory testing included permeability tests on wet bulk samples obtained during construction, and undisturbed Shelby tube samples obtained from drill holes after the wall had hardened. For ease of reference, we have included the results of the previous laboratory permeability tests (Attachment No. 2).

The subject work was being directed by Brown & Root Environmental of Houston, Texas, in accordance with their work plan dated October 14, 1993 (Attachment No. 3). Mr. Ernest Carter of Brown & Root was on-site to direct the work of the subcontractor, Continental Excavating, of West Sacramento, California. The equipment on-site consisted of a backhoe and small bulldozer. The contractor's personnel included an operator and a laborer.

Wahler representative, Mr. Michael Mooers, was on-site between October 26, 1993 and October 28, 1993, at the request of the Corps of Engineers, Sacramento District. Wahler's purpose was to observe the excavation and sampling, and to perform laboratory testing of selected samples. This report presents some of our observations of the field activities and the results of the laboratory testing.

2.0 FIELD OBSERVATIONS

The test wall was exposed by excavation with the backhoe in three different locations: (1) a deep trench at the west end of the test section between about Station 2+35 and 2+75; (2) a shallow trench between about Stations 1+80 and 2+20; and (3) a deep trench near the east end of the test section between about Stations 0+50 and 0+70.

2.1 Trench Between Stations 2+35 and 2+75

The purpose of this trench was to expose the end of the wall, if possible, and to examine a typical section of the wall constructed with a cement-bentonite slurry mix, and obtain Shelby tube and block samples for possible laboratory testing. The wall, near its western end, was exposed on the western face of the backhoe trench at about Station 2+75 (see Photo No. 1). As seen in the photo, the wall is marked by a purple color due to the application of phenothalene solution which reacts with the cement in the slurry mix.



In an adjacent section of the trench, the soil surrounding the hardened wall was removed to a depth of about 10 to 15 feet for a length of about 20 to 30 feet near Station 2+50, leaving a free-standing wall (see Photo No. 2). The wall appeared to be of uniform thickness (about 1 foot). The excavated free-standing wall appeared to be moderately hard, due to the influence of the cement. The cement-bentonite slurry and the soil appeared to be well-mixed. The soil comprising the wall appeared to be from the same depth as the surrounding natural soil. Several large tubular voids were noted in the wall. A shovel could be pushed all the way into one void. Close examination of the wall also indicated the presence of numerous small air voids. The air voids appeared to range in size from barely visible to about 1/4-inch in diameter.

2.2 Trench Between Stations 1+80 and 2+20

The purpose of the shallow trench between Stations 1+80 and 2+20 was primarily to expose and examine the upper part of the wall in the bottom of the trench, and to obtain Shelby tube samples for possible laboratory testing. Although not exposed to the same depth as the wall near Station 2+50, the wall at these Stations seemed to be similar to the wall at Station 2+50 (see Photo No. 3).

2.3 Trench Between Stations 0+50 and 0+70

The purpose of this deep trench was to examine a typical section of the wall constructed with the flyash-cement-bentonite slurry mix, and to obtain block samples for possible laboratory testing (see Photo No. 4). The soil surrounding the hardened wall was removed to a depth of about 10 feet. The wall was very hard, had a flat gray color, and seemed to consist primarily of cement and flyash. The wall appeared to be intensely laced with numerous air voids. The air voids were irregularly-shaped up to about 1/2-inch.

2.4 Sampling

A total of 10 Shelby tube samples were obtained at Station 2+00 and Station 2+50. The first two Shelby tube samples were obtained at Station 2+00 and were pushed into the wall using the back of the backhoe bucket. The remaining 8 Shelby tube samples, obtained from Station 2+50, were driven into the wall with a sledge hammer. All



samples were capped and taped, and transported to Wahler's laboratory in Palo Alto for possible testing. No tube samples were attempted at Station 0+50 because the wall was too hard to push or drive the Shelby tubes.

Large pieces of the wall from approximately Stations 0+50 and 2+50 were broken off with the backhoe (see Photo No. 5 and Photo No. 6). The pieces were carved in the field with a shovel to fit into 5-gallon buckets (see Photo No. 7). A total of 5 block samples (in buckets) were taken. Although the samples were not clearly identified in the field, we deduced that duplicate samples from each of two depths, approximately 4 feet and approximately 10 feet, were taken at about Station 2+50. In addition, one sample was recovered from Station 0+50 from a depth of about 8 feet. The duplicate samples from Station 2+50 were sent to Brown & Root in Houston, and the State Department of Water Resources (DWR) in Sacramento. Thus, three block samples were returned to Wahler's laboratory in Palo Alto for testing.

2.5 Field Permeability Tests

Two field permeability tests were attempted at approximately Station 2+50. The apparatus and test procedure were intended to be a variation on a proposed ASTM test procedure entitled *Standard Test Method of Field Measurement of Hydraulic Conductivity of Porous Materials Using the Two-Stage Borehole Procedure*, October 1990. Three-inch O.D. PVC casings were installed in two sample holes in the slurry wall at a depth of about 10 feet. Three-quarter inch plastic tubing was extended up to the ground surface as the trench was backfilled. At the ground surface, the tubing was connected to two rigid graduated standpipes. However, the tests were not successful due to an apparent leak somewhere below grade.

2.6 Backfilling and Site Restoration

The trenches were backfilled with the native materials. The material was placed in layers of about 12-inch thickness and compacted by light tamping with the backhoe bucket. The crown and slopes of the levee were restored to a neat appearance by the subcontractor (see Photo No. 8).



3.0 LABORATORY TESTING

The laboratory testing consisted of 4 flexible wall permeability tests. As requested by representatives of the Corps of Engineers, three tests were performed on samples trimmed from the three block samples contained in the 5-gallon buckets. It was felt that specimens trimmed from the block samples would be relatively free of the possible effects of sample disturbance normally associated with Shelby tube sampling. In addition, one permeability test was performed on one of the Shelby tube samples from Station 2+00. The permeability test results are summarized in Table 1.

3.1 Sample Preparation of Block Samples

The 5-gallon block samples were trimmed by hand to achieve 3-inch diameter by approximately 4-inch long specimens for laboratory testing. The trimming was accomplished with a chisel and hammer, knife, and wire saw, as required. The very hard sample from Station 0+50 required use of a hammer and chisel for the initial reduction of the sample (Photo No. 9), whereas the samples from Station 2+50 could be trimmed down with a sharp knife (Photo No. 10). The block samples were successively reduced in diameter until the specimen could be pressed into a 3-inch diameter by 1-inch high ring, or a 3-inch diameter by 6-inch high teflon-coated cutting tube (Photo No. 11). Final trimming was done with a knife or wire saw as the sample was gently pressed into the tube, until the desired length was achieved. The sample was then extruded from the cutting tube and prepared for testing.

3.2 Sample Preparation of Shelby Tube Samples

In order to minimize sample disturbance, the sample tube chosen for sample preparation was cut into a smaller section using a radial pipe cutter.

The section chosen for sample preparation was extruded using a hydraulically-operated ram capable of exerting the minimum force necessary to free the sample from the tube. The sample was extruded from the tube so that it traveled in the same direction as when it was sampled, again minimizing disturbance. The sample was then trimmed to a height of approximately 4 inches. With the aid of a special trimming device, which



completely supported the sample, the possibility of sample disturbance due to handling was significantly reduced.

3.3 Permeability Test Procedure

The procedure used to perform the permeability tests was in accordance with ASTM D-5084-90, *Test method for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter*. The following is a brief description of the test procedure used.

After the initial weight and volume measurements were determined, each specimen was placed in a triaxial cell, encased in a latex membrane and sealed to the bottom pedestal and top cap with rubber "O" rings. Both the bottom pedestal and top cap are fitted with porous stones which have permeabilities estimated to be at least 3 orders of magnitude greater than the samples tested. After securing the triaxial chamber, the cell was filled with water and transported to the saturation bay.

The laboratory is equipped with a panel of nine bays, with an individual pressure control to each bay, such that nine triaxial samples can be simultaneously saturated and/or consolidated at different individual pressures. Bleeding air regulators capable of delivering air pressure up to 140 psi are used to control the top, bottom, and chamber lines leading to the triaxial cells. Each saturation bay is also equipped with constant diameter Pyrex sight tubes, each with a cross-sectional area of 0.075 square inch, which connect with the base of the triaxial cell, and thus to the sample. The sight tubes are easily read to the nearest 0.01 cubic inch.

The samples were saturated using a combination vacuum-back pressure technique. A small vacuum was applied to the top and bottom sample lines to remove air trapped in the lines and to increase the initial saturation without a change in void ratio. A pressure of 70 psi was then incrementally applied to both the top and bottom sample pore fluid lines and the triaxial chamber to obtain a sufficient degree of saturation prior to the consolidation phase of the test. This increase in pore pressure and confining pressure forces air trapped in the sample and lines to be dissolved into solution, but results in no net stress application to the sample. In order to determine whether the back pressure applied was causing complete saturation, Skempton's "B" parameter was



measured for all samples. A value in excess of 0.95 was considered to represent a fully saturated condition. After achieving complete saturation, the chamber pressure was increased to 10 psi above the sample fluid pressure, giving the samples a net effective stress of 10 psi. This stress level is approximately equivalent to the stress level of the samples as they cured in the wall prior to sampling. The top and bottom drainage lines were then simultaneously opened, and the total volume of water expelled from each sample was monitored.

The permeability was determined by applying a constant pressure head of 2.3 feet (equal to a pressure of 1 psi) to the sample and monitoring the flow of water from bottom to top of the sample as a function of time, using calibrated, constant diameter sight tubes. The tests were run several times to confirm that permeability did not vary appreciably with time. The final permeability test results are summarized in Table 1.

After the completion of the laboratory testing, the trimmings from the block samples, and the unused Shelby tube samples were shipped to Brown & Root Environmental in Houston, Texas.

4.0 CLOSURE

It is not the intent of this report to provide a complete description of the activities related to the excavation and sampling of the slurry wall test section, or to draw any conclusions therefrom. We understand that detailed reports on the construction and testing, and results, conclusions and recommendations resulting therefrom, will be prepared by WES and the prime contractor, Brown & Root Environmental. Wahler Associates was not on-site continuously during the project, nor did we direct the work of the prime contractor, Brown & Root Environmental, or their subcontractors. Verification of conformance with the work plan, specifications, safety requirements, or any other requirements of the contract, was not our objective. Our purpose was to observe, at the request of the Valley Resident Office of the Sacramento District of the Corps of Engineers, and perform laboratory testing as directed by the Corps. This report presents a summary of some of our observations and the results of the laboratory testing.



TABLE 1

**SUMMARY OF "SOIL-SAW" SLURRY
WALL TEST SECTION
PERMEABILITY TEST RESULTS
NOVEMBER 1993**

Station	Approx. Depth (ft)	Type of Sample	Date Wall Installed	Date Sample Taken	Date Sample Transported	Age During Test (Days)	Water Content (%)	Dry Density (pcf)	Water Content (%)	Dry Density (pcf)	Hydraulic Gradient	As-Tested	
												Initial	As-Tested
0+50	8	Block	3/3/93	10/27/93	10/28/93	11/4/93	246	44.2	73.5	46.5	74.2	6.2	8.0x10 ⁻⁸
2+50	4	Block	3/3/93	10/27/93	10/28/93	11/4/93	246	51.2	67.0	55.3	67.6	5.8	2.8x10 ⁻⁷
2+50	10	Block	3/3/93	10/27/93	10/28/93	11/5/93	247	50.1	67.0	55.5	67.3	5.9	2.2x10 ⁻⁷
2+00	8-10	Tube	3/3/93	10/27/93	10/28/93	11/17/93	259	62.8	57.1	69.6	57.7	7.1	2.2x10 ⁻⁵



PHOTO NO. 1. END OF TRENCH AT APPROX. STA. 2+75, LOOKING WEST.
NOTE SLURRY WALL MARKED BY PURPLE COLOR.

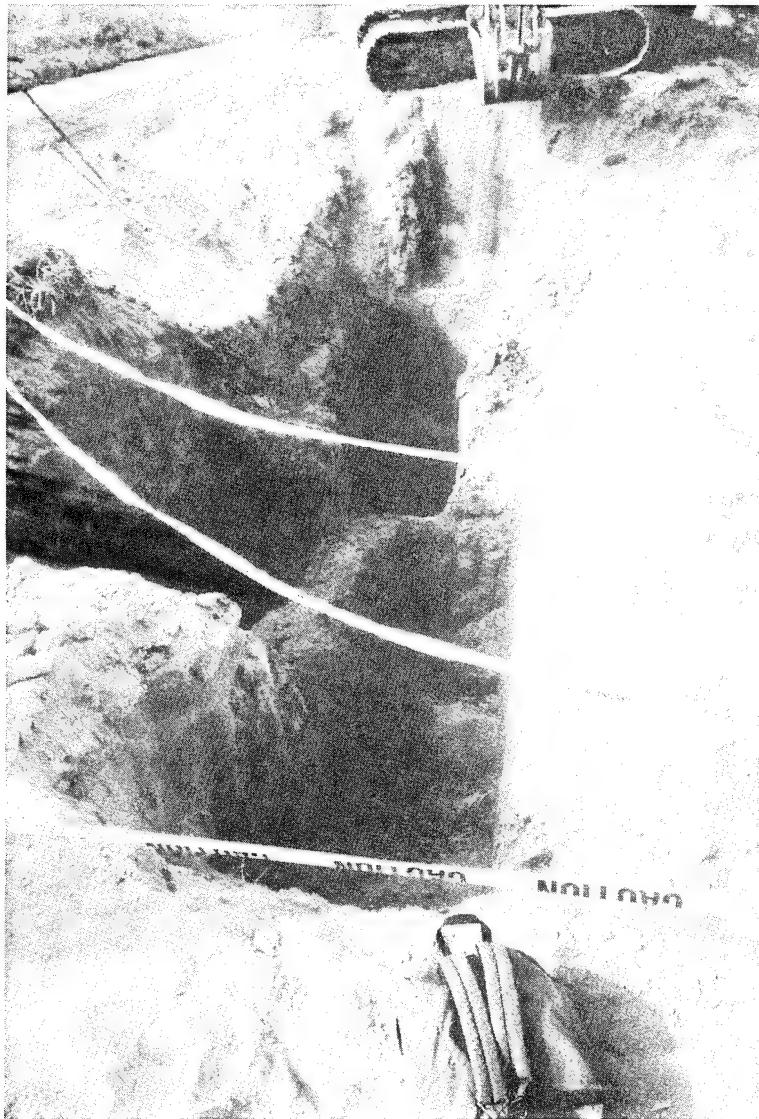


PHOTO NO. 2. TRENCH AT APPROX. STA. 2+50.
LOOKING WEST.



PHOTO NO. 3. TRENCH FROM APPROX. STA. 2+20
TO 1+80. LOOKING EAST.



PHOTO NO. 4. TRENCH AT APPROX. STA. 0+50



PHOTO NO. 5. EXCAVATING BLOCK SAMPLE OF SLURRY WALL FROM TRENCH AT STA. 0+50.



PHOTO NO. 6. BLOCK SAMPLE FROM STA. 0+50



PHOTO NO. 7. CARVING BLOCK SAMPLE INTO 5-GALLON BUCKET



PHOTO NO. 8. FINAL CONDITION OF LEVEE, LOOKING EAST



PHOTO NO. 9. INITIAL TRIMMING OF BLOCK SAMPLE FROM STA. 0+50
WITH HAMMER AND CHISEL.

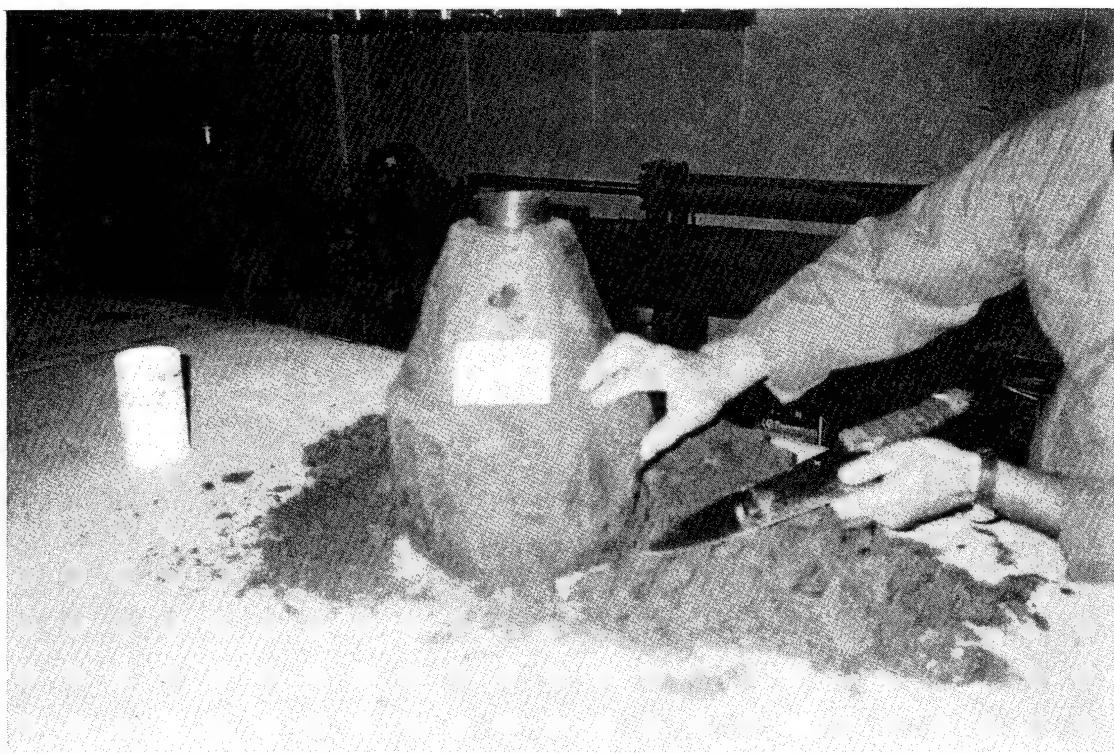


PHOTO NO. 10. INITIAL TRIMMING OF BLOCK SAMPLE FROM
STA. 2+50 WITH KNIFE.



Wahler Associates

COE-263W



PHOTO NO. 11. FINAL TRIMMING OF BLOCK SAMPLE FROM STA. 0+50



Brown & Root Environmental
TECHNOLOGY GROUP

DATE: November 10, 1993

TO: Michael R. Moores, Wahler Associates

FROM: Ernie Carter, Brown & Root

RE: Slurry designs used in CPAR test of SoilSaw

The Slurry designs used in our Sacramento test were as follows:

For the 0+50 location, the hard flyash/cement/bentonite wall
Gel was prepared by blending 21.4 pounds of premium grade bentonite with 2.8 pound of
dry lignosulfonate and 39.9 gallons of water. This mixture was pre hydrated for 24 hours.

We prepared the C/B slurry by blending 37.3 gallons of the above gel with 0.6 pounds of
CFR-3 (a super plasticizing admixture) and 88.7 pounds of type I portland cement.

The area we excavated from 2+30 to 2+65 showed a very uniform wall which had a shear
strength similar to the surrounding levee soil, about 8 to 10 tons per square foot. The
surface soils for the top 3 feet were cohesionless dry sands.

The C/B/Flyash wall at location 0+50 to 0+70 was made by adding 231.7 pounds of class F
flyash to 32.9 gallons of the above C/B slurry. This produced a very hard wall which was
estimated to be over 1000 psi in strength.

Both walls exhibited signs of entrained air in pockets of .2 to .4 inch diameter. These voids
did not appear to be interconnected and did not seem to impact permeability. The air
entrainment was most likely the result of use of dry additives with a non-Halliburton type
mixer system which did not have a de-aeration device.

ATTACHMENT NO. 1

TABLE 3

**SUMMARY OF "SOIL-SAW" SLURRY
WALL TEST SECTIONS
UNCONFINED COMPRESSIVE STRENGTH
TEST RESULTS**

Station	Depth (ft)	Type of Sample	Date Wall Installed	Date Sample Taken	Date Sample Transported	Date Sample Tested	Age During Test (Days)	Water Content (%)	Dry Density (pcf)	Peak Unconfined Compressive Strength (psi)
00+25	8-10	Undist.	3/3/93*	3/12/93	3/13/93	3/31/93	28	49.5	68.3	14.8 @ 2.9%
00+50	13	Bulk	3/3/93	3/3/93	3/13/93	3/31/93	28	43.4	75.4	32.9 @ 3.0%
00+57	8-10	Undist.	3/3/93	3/13/93	3/13/93	3/31/93	28	42.0	76.2	53.3 @ 2.7%
2+50	15	Bulk	3/4/93	3/4/93	3/13/93	4/1/93	28	59.5	64.2	22.6 @ 4.0%

*Assumed

ATTACHMENT NO 2



Brown & Root Environmental

PRDA SOILSAW PROJECT

DATE: October 14, 1993

TO: Kent Saugier, Project Manager

FROM: Ernie Carter, Principal Investigator

RE: Plan for excavation and sampling of previously formed wall
at Sacramento, Ca.

Test Goals

Our goal is to collect sufficient data to characterize the walls which were formed, to photograph cross-sections of the wall to indicate the probable uniformity of the wall and to determine the strength, width, and depth of the walls. A secondary goal is to attempt to determine the actual permeability of the walls. There is presently no reliable standard method of measuring permeability of a such walls in place.

The walls will be considered successful if they are of a uniform width and are free of large inclusions of soil. Physical property goals will be achieved on the cement bentonite walls if the in-place permeability is lower than 1×10^{-6} cm/sec with strength greater than 15 psi. Core drilled samples on other walls have produced lower quality samples than push-tube samples. Therefore we plan to take only push-tube samples. This will be done by pushing or hammering a shelby tube into the wall.

This sampling project will be considered successful if the majority of the tests outlined below can be completed and the data obtained.

Scope of Work

Our scope of work calls for us to excavate and sample the wall formed during the tests of the SoilSaw™ equipment at the Corps of Engineers spoils pit levee in Sacramento, California. This work was done for our CPAR contract with the Corps of Engineers.

We plan to excavate sections of the levee, remove sections of the wall, push Shelby tubes through them, and lab test the cores to determine relative permeability and compressive strength of the material. We also plan to attempt to evaluate width and continuity of large excavated sections of the wall.

Our primary objective in this work is to verify the physical presence of the wall and its dimensions and to make observations on the vertical and lateral uniformity of the wall.

Corps of Engineers personnel will be invited to observe and SoilSaw project engineers will be present on site for the actual excavation.

The project will begin as soon as practical.

The work is expected to take 2 full working days. The levee will be restored to a serviceable condition immediately following the excavation.

PRE-MOBILIZATION PREPARATIONS

- Review this scope of work with both the Vicksburg and Sacramento Corps of Engineers offices.
- Contract with a soils testing firm to provide lab testing services.
- Contract with another local firm to provide excavation services.

- Schedule excavation with options for weather delays.
- Review health and safety plan used in construction.

Sampling Wall

- Position the backhoe straddling the wall and excavate a 25 foot long section of the levee to 5 foot of depth, excavate an additional 3 feet on both sides of the wall laying the walls back as directed by our on-site registered professional engineer
- Clean the exposed surface of the wall with air hose or manually trim the soil away from the exposed wall with a shovel.
- Photograph and measure width of wall with a tape measure.
- Attempt to break off large pieces of the exposed wall and bring them to the surface with the backhoe. Obtain push-tube samples. Trim other large pieces with a saw or knife to fit in a 5 gallon plastic bucket for shipment to the testing laboratory. Add 1 pint of water to the bottom of each bucket before sealing the lid, to help preserve moisture. Attempt to recover 6 discrete samples.
- Photograph and video tape cross-section of wall.
- Use pocket penetrometer to estimate strength of wall.
- Continue excavation to progressively greater depths till soil instability limits further access or bottom of wall is reached. Attempt to obtain section of wall with intact interface between bottom of wall and undisturbed soil.
- Fill in excavation compacting soil in 12 inch lifts.
- Move to new position and repeat excavation as time permits.
- Regrade surface of levee to original condition.

Laboratory Testing

- Core sections of wall recovered from site and test for permeability and compressive strength.
- Compressive strength will be tested on a device which generates a hard copy of the stress vs strain curve to evaluate elastic yield of the cores.

Land Restoration

- The levee disturbed by the work will be filled in and leveled. Any debris left from operations will be removed.

Final Report

A report shall be prepared showing all information in both tabular and graphical format as well a technical discussion of all observed conditions.

Schedule

The mobilization will commence as soon as our schedule permits and is estimated to require 2 days of field work.

REPORT DOCUMENTATION PAGE

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